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COMPARISON OF FATIGUE ENHANCING FASTENER SYSTEMS IN ALUMINUM-LITHIUM MATERIALS

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MATERIALS ENGINEERING BRANCH
SYSTEMS SUPPORT DIVISION

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NOTICE

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Aluminum alloys represent 70 to 80 percent of an aircraft's structural weight. Improvements to structural materials have been concentrated in the areas of increased stiffness and reduction in density. Aluminum-Lithium alloys offer reduction in density of 8 to 10 percent while matching strength and fracture toughness values of traditionally used alloys. These materials have also shown equivalent or superior fatigue performance and a general resistance to corrosion.

Although much work has been performed evaluating tensile properties, crack propagation rates, and fracture toughness, very little has been published looking at the material in a fastened state. One of two prime concerns is stress corrosion cracking caused by an imposed stress from radial interference (expansion) in the short transverse grain direction. The second area, fatigue performance, is typically characterized using ASTM type smooth or notched fatigue coupons. These investigations while addressing notched conditions do not take into account fatigue enhancement processes or stress distributions resulting from fastener design. The purpose of this effort was to generate comparative data on the performance of selected fatigue rated fastener systems in Al-Li and a base line alloy 2024.

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PREFACE

This report was prepared by the Materials Engineering Branch (WL/MLSE), Systems Support Division, Materials Directorate, Wright Laboratory, Wright-Patterson Air Force Base, Ohio, under Program element 62102F, Project 2418, "Metallic Structure Materials." Task 241807, "Systems Support," Work Unit 24180703, "Engineering and Design Data."

The work reported herein was performed during the period June 1989 to November 1990, under the direction of the author, Neal R. Onkto (WL/MLSE). The author wishes to thank Dr. Kumar Jata for his guidance, and messers Donald Woleslagel, Robert Hicks, and John Eblin (University of Dayton Research Institute) and Mr Jack Coate (WL/MLSE) for their assistance and efforts.

Aerospace hardware was generously supplied by Hi-Shear Corporation, Deustch Fastener Corporation, and Fatigue Technology Incorporated. Their cooperation and support was greatly appreciated.

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SECTION 1

Introduction

Although much work has been performed evaluating tensile properties, crack propagation rates, and fracture toughness, very little has been published looking at the material in a fastened state. One of two prime concerns is stress corrosion cracking caused by an imposed stress from radial interference (expansion) in the short transverse grain direction. The second area, fatigue performance, is typically characterized using ASTM type smooth or notched fatigue coupons. These investigations while addressing notched conditions do not take into account fatigue enhancement processes or stress distributions resulting from fastener design.

Conventional methods of assembly using drilled holes and mechanical fastening create flaws or sites of stress concentration. A key to retarding crack initiation and growth in fuselage and wing sections has been to create a residual stress which acts to reduce stress amplitudes under cyclic load by providing a compressive stress field around the hole. This is accomplished by interference fit when the fastener exceeds the hole diameter by a specified amount or through "cold work" where an oversized mandrel is pulled through a removable lubricated sleeve placed inside the hole.

The purpose of this effort was to generate comparative data on the performance of selected fatigue rated fastener systems in two Al-Li alloys and a base line alloy 2024.

An investigation was conducted in 1983 to evaluate stress corrosion cracking characteristics in 7075-T6 aluminum. The current evaluation parallels those earlier conditions. The 8090-TU51 alloy was also available in thick sections. The test blocks used were machined from cubes. Each cube is basically "hollowed out" leaving a single test coupon with access to three grain orientations. Final thickness of each side was reduced to 0.380 inch. Stress corrosion cracking tests were performed according to ASTM G-44 "Alternate Immersion Stress Corrosion Testing in 3.5 percent Sodium Chloride Solution" for 32 days. Observations included the amounts of time required for cracks to initiate in the 8090 material for each of the systems tested. See Appendix A.

A fatigue performance comparison was also conducted. Fatigue testing via constant amplitude loading was conducted using open hole specimens as a control. Aluminum alloys 2024, 2090, and 8090 were selected because of their competitive nature. The coupon design selected for fatigue testing was a flat 2 in. wide by 0.3125 in. thick specimen with a centered hole. Fasteners selected for this effort, Taper Lok and Hi-Lok type pin and threaded collar systems, are among the most frequently used in the aerospace industry. A test matrix for fatigue tests is shown in Table 1.

Some of the fastener holes were cold worked using the split sleeve system. All fatigue specimens were cycled using constant amplitude loading, R=0.1, at 30 ksi gross area stress. Any fatigue enhancement over the control specimens or significant difference in fatigue performance is reported.

No loads were transferred by the pins in the test coupon. The intent was to study the effects of installation parameters on fatigue life of the alloys selected.

TABLE 1

Fatigue Test Matrix

Specimen Condition & Fastener System	2024-T8 Flush	2024-T8 Prot	8090-TU51 Flush	8090-TU51 Prot	2090-T8E41 Flush	2090-T8E41 Prot
Open Hole Control	5	5	4	5	5	5
Cold Work/Hi-Lite ST/Std Int. Fit	-	-	4	4	4	4
Cold Work/Hi-Lite ST/Mod. Int Fit	4	4	-	-	-	-
Hi-Lite ST/ Clearance Fit	4	4	4	-	4	4
Hi-Lite ST/ Transition Fit	4	-	4	-	4	4
Hi-Lite ST/ Low Int Fit	-	4	-	-	-	-
Taper-Lok/Low Int Fit	-	-	4	-	-	-
Taper-Lok/Std Int Fit	4	4	-	-	4	4

Although it was strongly desired to keep interference fits equal among the three materials selected, it was found that the tooling recommended produced different hole sizes in the fatigue coupons between the three alloys and larger hole sizes than predicted in the stress corrosion test blocks. Hole conditions described as open hole, transition fit, and low, standard, or moderate interference are described in more specific terms in the appendix. See Tables 2, 3 and Appendices B and C.

All fatigue coupons (8090, 2090, and 2024 aluminum alloys) and one half of the stress corrosion blocks (8090 material only) were tested in the as machined state. The other half of the corrosion test blocks (8090 material only) were shot peened to an Almen intensity of 0.012 using MI 230 shot at 200 percent coverage.

Table 2

Stress Corrosion Fit Parameters

Taper-Lok (TL) Standard Interference (SI)

A-3	A-1	B-1	Shot Peened (SP)
D-1	B-6	B-2	Bare (B)

	Head Protrusion (inch)	Interference (inch)
Avg	0.109 + 48	0.0023
Min	0.061 + 48	0.0013
Max	0.162 + 48	0.0034

Hi-Lite (HL) Transition Fit (TF)

B-4	D-3	C-2	Shot Peened (SP)
B-5	C-5	C-1	Bare (B)

	Hole Size (inch)	Interference (inch)
Avg.	0.2482	0.0008
Min.	0.2470	0.0020
Max.	0.2502	-0.0012 (oversize)

Hi-Lite (HL) Moderate Interference (MI)

A-4	B-3	D-5	Shot Peened (SP)
C-4	A-2	D-4	Bare (B)

	Hole Size (inch)	Interference (inch)
Avg.	0.2447	0.0043
Min.	0.2443	0.0047
Max.	0.2455	0.0035

Cold Work & Hi-Lite (CW/HL)			Low Interference (LI)
C-6	D-6	C-3	Shot Peened (SP)
A-5	D-2	A-6	Bare (B)

Starting Hole Size (inch)		% Expansion (inch)
Avg.	0.2405	4.4 %
Min.	0.2395	4.8 %
Max.	0.2455	2.2 %

Mandrel & Sleeve Diam 0.251 inch

Final Hole Size		Interference
Avg.	0.2475	0.0015
Min.	0.2466	0.0024
Max.	0.2480	0.0010

Fastener Diam 0.249 inch

TABLE 3

Fatigue Coupon Fit Parameters

Average Fastener Interferences (Inch)

Fastener System	Materials		
	8090	2090	2024
Taper-Lok	0.0015	0.0025	0.0030
Hi-Lite ST	-0.0018[1]	-0.0022[1]	-0.0019[1]
Hi-Lite ST	-0.0004[2]	-0.0003[2]	0.0012
Hi-Lite ST[3]	0.0025	0.0021	0.0040

1 Clearance Fit

2 Transition or Neat Fit

3 Interference fit in conjunction with 3 percent cold expansion for fatigue

SECTION 2

Fastener Systems and Installation Procedures

Hi-Lite ST

Hi-Lite ST fasteners and torque off collars were supplied by the Hi-Shear Corporation. The Hi-Lite ST pin is a lighter weight version of the conventional Hi-Lok designed to meet the same mechanical strengths. HST 10AG-8-5 and HST 11AG-8-5 protruding and flush head styles were used for fatigue testing. HST 11AG-8-6 pins were used for the stress corrosion tests in the flush head style only. All pins were secured with HST 79-CY-8 collars.

Taper-Lok

Taper-Lok pins and nuts were also selected for this program. TL 100-4-6 and TL 200-4-6 pins (flush and protruding head styles) were installed in the fatigue coupons, while TL 100-4-7 flush head pins were used in the stress corrosion blocks. The installation of the Taper-Lok pins was completed with TLN 1001L4 12 point nuts with captivated washers. These parts were supplied by Deutsch Fastener Corporation.

Both fastener systems are widely used in the aerospace industry with confidence. Each of these systems was protected with a coating galvanically compatible with aluminum alloys. Torque on the fastener systems was applied equivalently. No sealants were used.

Cold Work

Tooling for the Boeing "split sleeve" process was supplied by Fatigue Technology Incorporated. Cold hole expansion using a portable power pack was accomplished in-house. Mandrels and sleeves were selected for "cold expansion" to size for both protruding head and flush head styles. The "countersink cold expansion" tooling used provides simultaneous cold work of the hole and countersink areas. None of the cold worked holes were post reamed. Differences in material response precipitated the use of separate mandrels and sleeves for the 2090 material than was used for the 2024 and 8090 alloys. Tooling was selected to produce 3.5 to 4.0 percent expansion before fastener installation. This process was used in conjunction with the Hi-Lite fastener system only. See Appendix A.

An evaluation of cold worked holes revealed a very slight taper through the thickness of 0.0003 to 0.0007 inches for 2024, 0.0005 to 0.0007 inches for 2090, and 0.0004 to 0.0007 inches for 8090 over approximately 0.375 inch. With the split sleeve process a rib is left in the bore as the mandrel is pulled through the material. The depth of the rib was 0.005 in. for 2024, 0.003 in. for 2090, and 0.003 in. for 8090. The rib is narrow in breadth and did not impede fastener installation.

SECTION 3

Materials

2024

This heat treatable Al-Cu alloy was selected in the T8 condition. Typical tensile strengths for this temper are 65 ksi ultimate, 60 ksi yield strength and 6 percent elongation. This alloy is widely used in aircraft structure in a variety of tempers tailored for strength or toughness.

2090

This material was developed by Alcoa as a high strength, low density replacement for 7075-T6. A data base developed as part of an Aluminum Lithium Cooperative Test Program characterized the T8E41 0.5 inch plate donated for this effort. The plate was produced in the June/October 1985 time frame. Properties reported in AFWAL-TR-87-77 "Aluminum Lithium Alloy 2090-T8E41 0.5 Inch and 1.65 Inch Plate Mechanical Test Data" were 86 ksi ultimate tensile strength, 81 ksi yield, and 6 percent elongation.

8090

The need for a damage tolerant, low density, medium strength material led to the development of this alloy. A 4 inch plate was received from Northrop Aircraft Division in the TU51 temper. Approximately 2 in. by 2 in. by 2 in. cubes were sectioned from the plate for stress corrosion testing. The thickness of the test blocks was 0.380 inch.

The plate used was manufactured by Alcan (vintage 1986) as Lital "A" in the TU51 condition. Thick plate was necessary to enable stress corrosion testing of all three grain directions (Longitudinal, Long Transverse, and Short Transverse). Typical mechanical properties were reported as 65 to 71 ksi ultimate tensile strength, 48 to 62 ksi yield and 4.4 percent average elongation. Fracture toughness values reported by Northrop are 24 ksi $\sqrt{in.}$ (L-T), 23 ksi $\sqrt{in}$ (T-L), and 16 ksi $\sqrt{in.}$ (S-L) for each orientation. Tests conducted at the Materials Directorate under a previous program, WRDC-MLS-89-56 "Short Transverse Properties of 8090-TU51 Aluminum Plate," confirmed an ultimate tensile strength of 62 ksi and a yield strength of 48 ksi. Elongation and fracture toughness were somewhat lower at 2 percent vs 3 percent for the short transverse orientation and 15.3 ksi $\sqrt{in.}$ respectively. Additional tests report a sensitivity to stress corrosion in the short transverse orientation at stresses between 7 and 13 ksi. This is somewhat lower than literature data shown for resistance to stress corrosion for 7075-T651 plate tests performed using 3.5 percent NaCl solutions and alternate immersion.

SECTION 4

Test Results and Discussion

Dimensional tolerances for the holes drilled were difficult to control. This resultant variation between alloys would be of concern for a mixed stack of materials or materials drilled on line with the same tooling.

The amount of cold work selected for stress corrosion testing was excessive for an edge margin of 1.5 times the diameter of the fastener. Cracks occurred frequently in the test blocks before fasteners were installed. Moderate interference levels (0.0035 to 0.0050 inches interference) used without cold work also produced cracks. Bare specimens at this interference level cracked before shot peened specimens during the test. See Appendix B.

Five out of six stress corrosion test blocks using the tapered fastener system survived without cracking at the levels of interference tested. The one block that did partially crack was in the bare condition. Depletion of the cadmium coating on the fastener heads was observed after 18 days of stress corrosion testing illustrating its sacrificial nature of corrosion protection.

The 2090-T8E41 alloy exhibited better fatigue life overall when compared to 8090-TU51 and 2024-T8 materials. Both 2090-T8E41 and 8090-TU51 exhibited higher fatigue performance for open hole conditions than the 2024-T8 material.

Interference fit significantly improved fatigue life for all three materials. Fatigue life was most enhanced by the cold work process in conjunction with interference fit. Several of these specimens failed away from the hole. When possible the specimen was regripped until failure occurred through the hole. The tapered pin fastener system also provided significant improvements in fatigue life. Some of these specimens also failed away from the hole the first time. See Figures D-12 and D-13.

The 8090 material failed in a most unorthodox manner regardless of interference level or fastener system used. Cracks originating at the holes transitioned in propagation to a direction almost parallel to the load applied before failure. See Figure D-11.

Section 5

Conclusions

1. Shot peening was beneficial for increasing the resistance of 8090-TU51 to stress corrosion cracking.

2. Cracks occurred initially as the holes were cold worked using approximately 4 percent cold hole expansion at edge margins of 1.5. The edge margin is a ratio of the distance from the free end of the material to the center of the hole divided by the diameter of the hole. See Appendix B.

3. Straight sided pins in transition fit and tapered pins at standard levels of interference did not produce cracks of the same intensity as cold worked holes or moderate levels of interference. See Figures B-9 through B-14.

4. Open hole fatigue life was highest for the 2090-T8E41 alloy followed closely by the 8090-TU51 material. Both aluminum-lithium alloys were superior to 2024-T8. See Appendix D.

5. Standard levels of interference fit dramatically improved fatigue life. Overall the best fatigue performance was accomplished in the 2090 & 8090 material from the use of cold hole expansion. This superior performance in the 2024 alloy was matched by the tapered pin fastening system.

6. Both the cold work/straight pin combination and the tapered pin system at the levels of interference used frequently forced the first failure of the fatigue coupon away from the hole for both protruding and countersunk head styles in the 2000 series alloys illustrating the fatigue enhancement properties of these systems.

7. The stress corrosion data generated in this effort for the cold work (4.4 percent with 0.0015 inch interference fit) system tested in 8090-TU51 was completely opposite of that generated and reported in AFWAL-TR-83-4028 "Evaluation of Stress Corrosion Cracking Characteristics of Selected Fastener Systems in 7075-T6 Aluminum" (3.5 percent cold work and 0.0020 inch interference fit) where the cold working procedure did not initially crack the blocks and blocks that were shot peened showed no signs of cracking.

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2. MIL-HDBK-5E "Metallic Materials and Elements for Aerospace Vehicle Structures," June 1987.

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4. "Damage Tolerant Design Handbook" Metals & Ceramics Information Center Battelle Columbus Laboratories, Columbus, Ohio, Dec 1983.

5. "Aluminum Lithium Alloy 2090-T8E41 0.5 Inch and 1.65 Inch Plate Mechanical Test Data" AFWAL-TR-87-77, July 1987.

6. "Aerospace Structural Metals Handbook" Battelle Columbus Laboratories, Columbus, Ohio, October 1972.

7. AFWAL-TR-83-4028 "Evaluation of Stress Corrosion Cracking Characteristics of Selected Fastener Systems in 7075-T6 Aluminum," June 1983.

8. ASD-TR-72-111 "Fatigue and Stress Corrosion Tests of Selected Fastener/Hole Processes," January 1973.

APPENDIX A

Test Specimen Plan Views

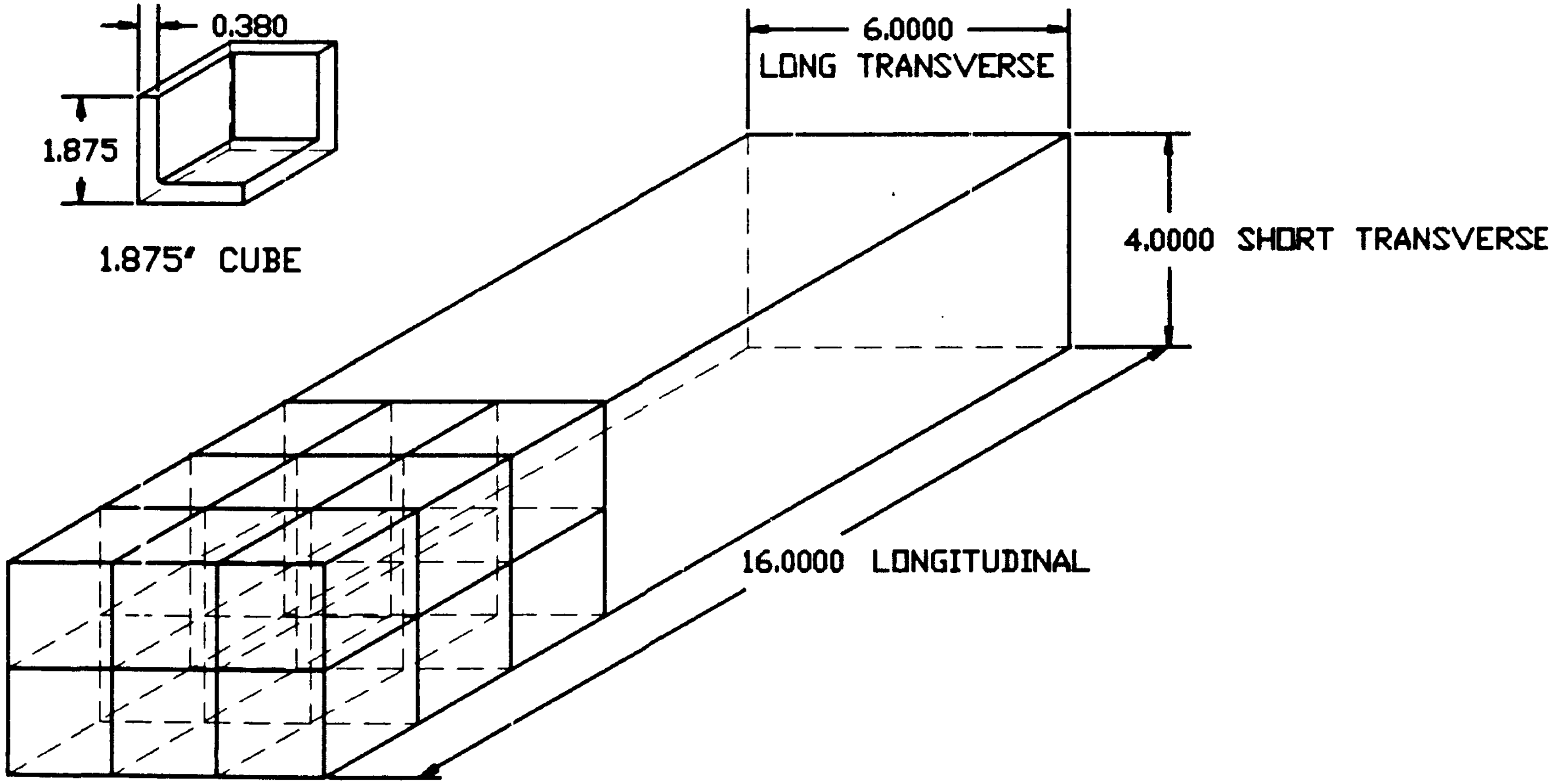


Fig A-1. 8090-TU51 4" Plate Stress Corrosion Blocks

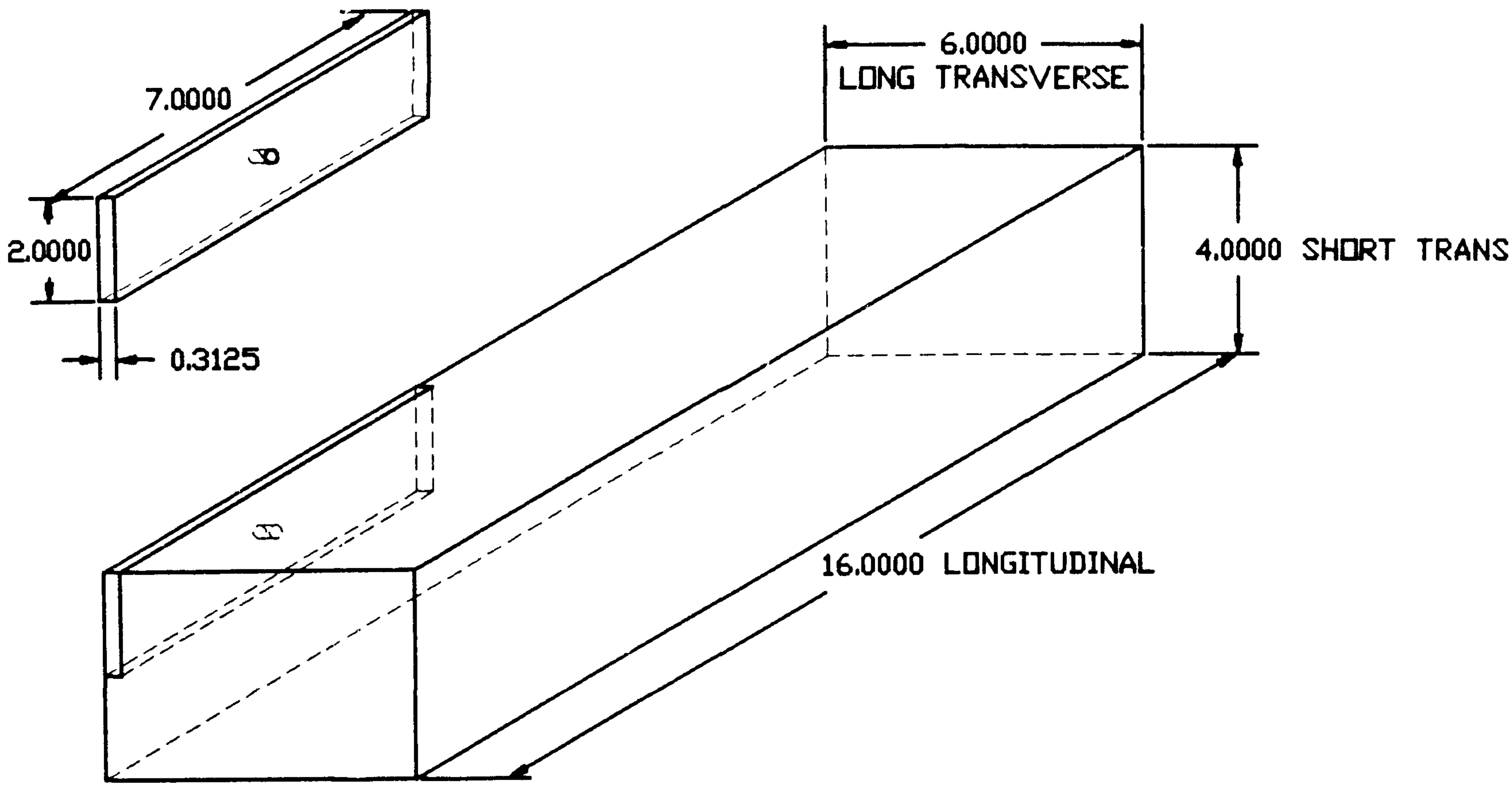


Fig A-2. 8090-TU51 4" Plate Fatigue Test Coupons

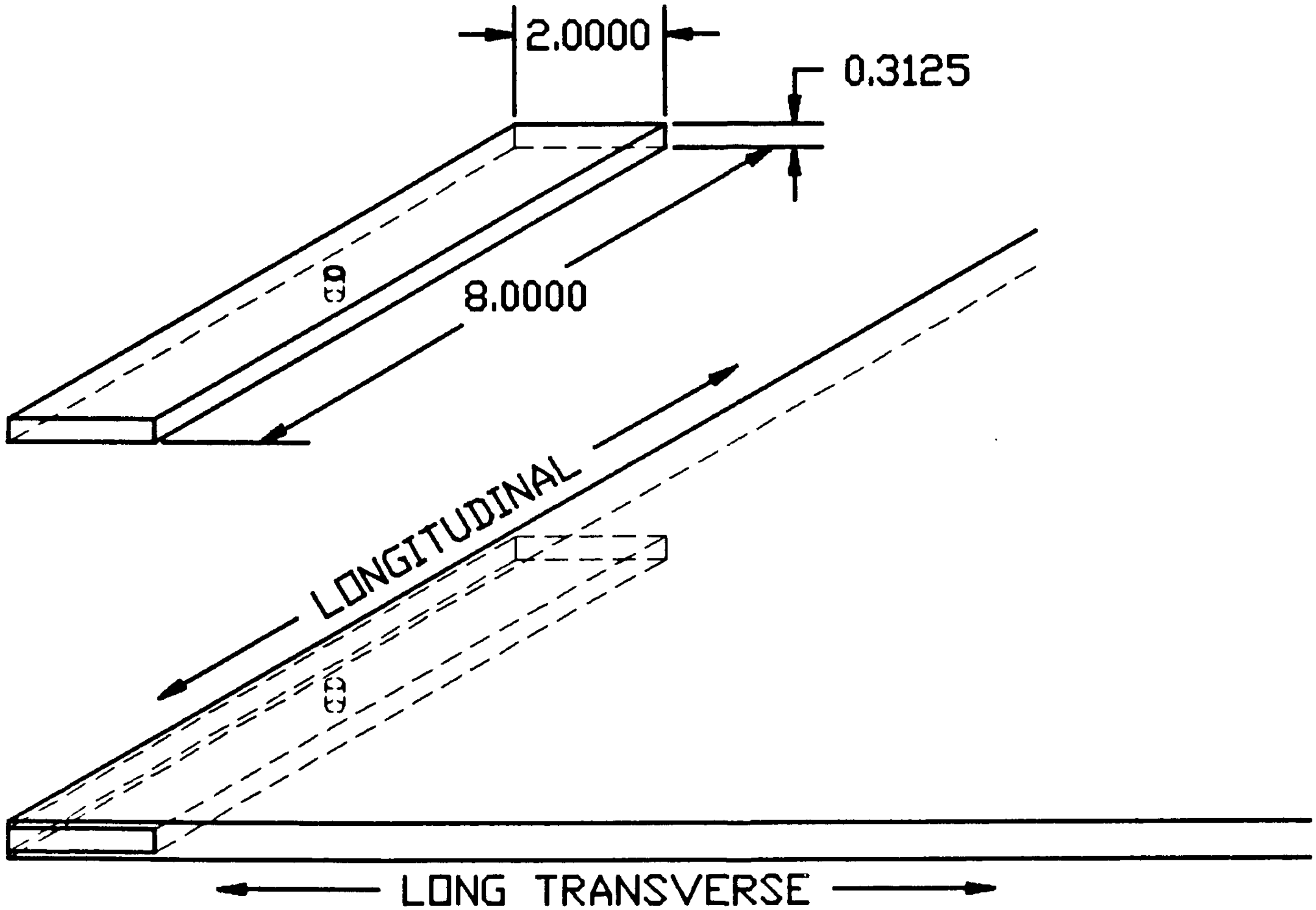
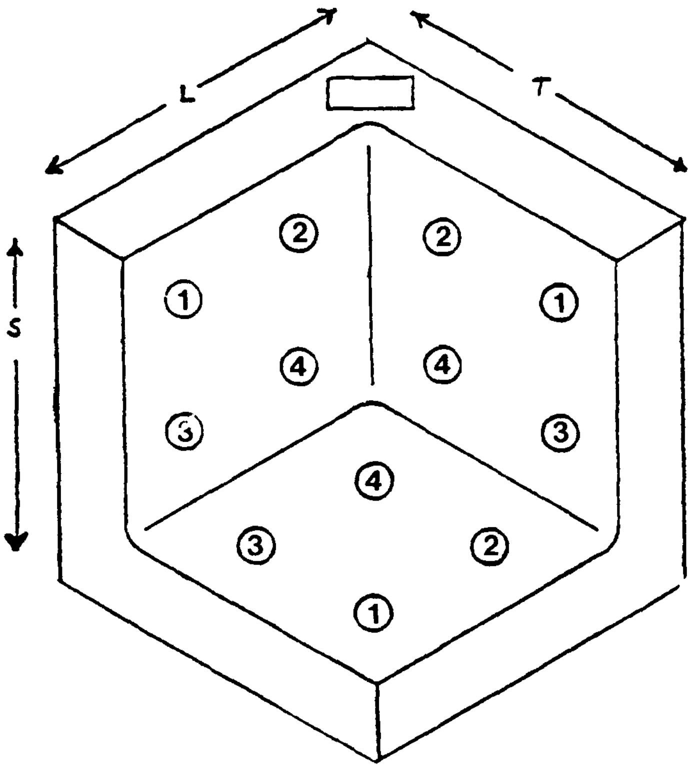


Fig A-3. Plan View for 2090-T8E41 and 2024-T8 Plate

Appendix B

Levels of Interference Fit for Stress Corrosion Test Blocks and Test Results



Bare/Taper-Lok/Standard Interference

D-1			B-6		B-2	
	1	.0019	1	.0024	1	.0030
	2	.0020	2	.0023	2	.0028
(SL)	3	.0015	3	.0027	3	.0024
	4	.0021	4	.0024	4	.0021
	1	.0027	1	.0016	1	.0023
(ST)	2	.0026	2	.0021	2	.0026
	3	.0020	3	.0013	3	.0019
	4	.0026	4	.0016	4	.0027
	1	.0014	1	.0029	1	.0026
(LT)	2	.0028	2	.0015	2	.0034
	3	.0027	3	.0023	3	.0029
	4	.0028	4	.0015	4	.0029

Shot Peened/Taper-Lok/Standard Interference

A-3			A-1		B-1	
	1	.0023	1	.0019	1	.0025
	2	.0021	2	.0014	2	.0029
(SL)	3	.0025	3	.0026	3	.0027
	4	.0021	4	.0018	4	.0021
	1	.0021	1	.0024	1	.0025
(ST)	2	.0029	2	.0020	2	.0018
	3	.0028	3	.0023	3	.0024
	4	.0024	4	.0021	4	.0022
	1	.0016	1	.0024	1	.0024
(LT)	2	.0022	2	.0019	2	.0025
	3	.0022	3	.0021	3	.0024
	4	.0022	4	.0018	4	.0022

Bare/Hi-Lite ST/Transition Fit

B-5	1	.0010	C-5	1	.0005	C-1	1	.0009
	2	.0010		2	.0005		2	.0010
(SL)	3	.0012		3	.0010		3	.0012
	4	.0010		4	.0010		4	.0010
	1	.0010		1	.0010		1	.0012
	2	.0005		2	.0006		2	.0009
(ST)	3	.0013		3	.0000		3	.0010
	4	.0012		4	.0004		4	.0007
	1	.0000		1	.0010*		1	.0001
	2	.0005		2	.0000*		2	.0003
(LT)	3	.0005		3	.0000*		3	.0002
	4	.0005		4	.0000		4	.0002

* Oversize Hole

Shot Peened/Hi-Lite ST/Transition Fit

B-4	1	.0016	D-3	1	.0010	C-21	1	.0020
	2	.0013		2	.0005		2	.0019
(SL)	3	.0012		3	.0015		3	.0013
	4	.0013		4	.0002		4	.0000
	1	.0012		1	.0017		1	.0015
	2	.0008		2	.0008		2	.0015
(ST)	3	.0009		3	.0010		3	.0008
	4	.0010		4	.0005		4	.0015
	1	.0008		1	.0008		1	.0005*
	2	.0008		2	.0008		2	.0000
(LT)	3	.0007		3	.0009		3	.0012
	4	.0007		4	.0005		4	.0010

* Oversize Hole

Bare/Hi-Lite ST/Moderate Interference

C-4	1	.0043	A-2	1	.0043	D-4	1	.0046
	2	.0042		2	.0043		2	.0047
(SL)	3	.0042		3	.0042		3	.0047
	4	.0042		4	.0043		4	.0046
	1	.0040		1	.0040		1	.0041
	2	.0042		2	.0040		2	.0039
(ST)	3	.0040		3	.0041		3	.0040
	4	.0044		4	.0041		4	.0041
	1	.0038		1	.0038		1	.0043
	2	.0041		2	.0041		2	.0042
(LT)	3	.0042		3	.0042		3	.0042
	4	.0043		4	.0041		4	.0041

Shot Peened/Hi-Lite ST/Moderate Interference

A-4		1	.0044	B-3	1	.0045	D-5	1	.0044
		2	.0044		2	.0045		2	.0044
	(SL)	3	.0045		3	.0046		3	.0043
		4	.0046		4	.0046		4	.0043
		1	.0043		1	.0043		1	.0042
		2	.0044		2	.0043		2	.0042
	(ST)	3	.0044		3	.0035		3	.0042
		4	.0045		4	.0045		4	.0044
		1	.0044		1	.0045		1	.0041
		2	.0045		2	.0045		2	.0040
	(LT)	3	.0045		3	.0043		3	.0040
		4	.0046		4	.0044		4	.0043

Bare/Cold Work/Hi-Lite ST/Low Interference

A-5		1	.0018	D-2	1	.0010	A-6	1	.0011
		2	.0020		2	.0015		2	.0012
	(SL)	3	.0020		3	.0013		3	.0020
		4	.0025		4	.0015		4	.0015
		1	.0018		1	.0012		1	.0014
		2	.0010		2	.0010		2	.0001
	(ST)	3	.0015		3	.0012		3	.0010
		4	.0024		4	.0017		4	.0015
		1	.0020		1	.0010		1	.0017
		2	.0020		2	.0015		2	.0020
	(LT)	3	.0020		3	.0020		3	.0020
		4	.0022		4	.0020		4	.0017

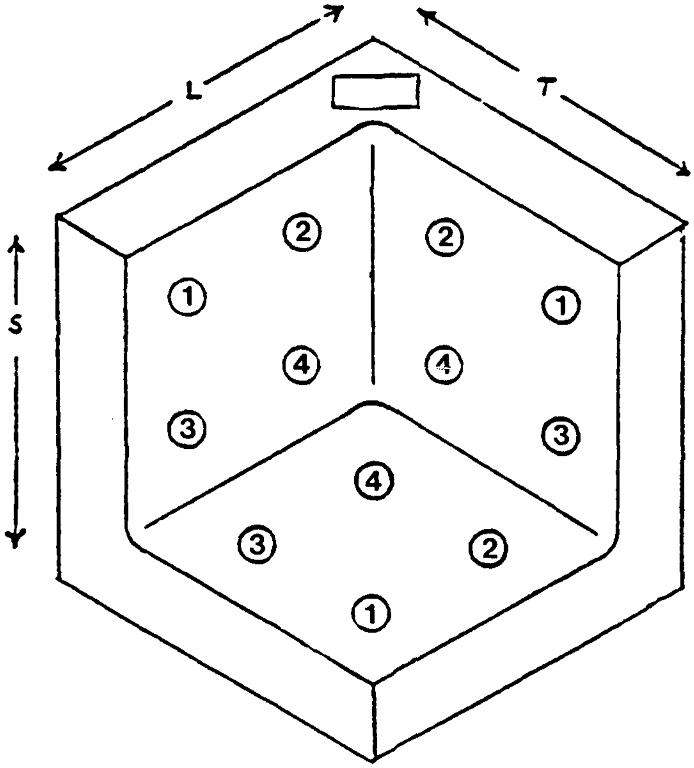
Shot Peened/Cold Work/Hi-Lite ST/Low Interference

D-6		1	.0011	C-3	1	.0020	C-6	1	.0005
		2	.0015		2	.0023		2	.0006
	(SL)	3	.0015		3	.0020		3	.0010
		4	.0015		4	.0022		4	.0015
		1	.0011		1	.0012		1	.0010
		2	.0015		2	.0010		2	.0007
	(ST)	3	.0010		3	.0020		3	.0012
		4	.0015		4	.0020		4	.0015
		1	.0015		1	.0010		1	.0012
		2	.0012		2	.0014		2	.0012
	(LT)	3	.0015		3	.0020		3	.0015
		4	.0015		4	.0015		4	.0016

STRESS CORROSION TEST BLOCKS

Explanation for Codes Used

B	Bare Condition
SP	Shot Peened Surface
FCD	Fastener Cadmium Depletion
TL	Taper I ok Fastening System
HL	Hi Lite Fastening System
CW	Cold Work of Hole Through Thickness
TF	Transition Fit
LI	Low Interference Fit
SI	Standard Interference Fit
MI	Moderate Interference Fit
TF	(oversize hole) to .0020 inch
LI	.0010 to .0025 inches
SI	.0010 to .0035 inches
MI	.0035 to .0050 inches
CW	2.2 to 4.8 % expansion



TEST Initiated

Specimen	I.D.	Location	Date
D-2	B/CW/HL/LI	Edge - 3 SL	26 Oct 90
		Edge - 1 LT	26 Oct 90
A-6	B/CW/HL/LI	Edge - 3 SL	26 Oct 90
D-6	SP/CW/HL/LI	Edge - 3 SL	26 Oct 90
C-3	SP/CW/HL/LI	Edge - 3 SL	26 Oct 90
C-6	SP/CW/HL/LI	Edge - 1 SL	26 Oct 90
D-2	B/CW/HL/LI	Edge - 3 SL	29 Oct 90
		Edge - 1 LT	29 Oct 90
		3 - 4 ST	29 Oct 90
A-6	B/CW/HL/LI	Edge - 3 SL	29 Oct 90
		Edge - 3 SL	29 Oct 90
		Edge - 3 ST	29 Oct 90
D-6	SP/CW/HL/LI	Edge - 3 SL	29 Oct 90
		3 - 4 SL	29 Oct 90
		Edge (PC) - 1 SL	29 Oct 90
		Edge - 1 ST	29 Oct 90
		Edge - 3 ST	29 Oct 90
		3 - 4 ST	29 Oct 90

Specimen	I.D.	Location	Date
C-3	SP/CW/HL/LI	Edge - 3 SL	29 Oct 90
		3 - 4 SL	29 Oct 90
		Edge - 1 ST	29 Oct 90
		Edge - 3 ST	29 Oct 90
		3 - 4 ST	29 Oct 90
C-6	SP/CW/HL/LI	Edge - 1 SL	29 Oct 90
A-5	B/CW/HL/LI	Edge - 1 SL	29 Oct 90
D-2	B/CW/HL/LI	Edge - 3 SL	30 Oct 90
		Edge - 1 LT	30 Oct 90
		3 - 4 ST	30 Oct 90
A-6	B/CW/HL/LI	Edge - 3 SL	30 Oct 90
		Edge - 3 ST	30 Oct 90
D-6	SP/CW/HL/LI	Edge - 3 SL	30 Oct 90
		3 - 4 SL	30 Oct 90
		Edge (PC) - 1 SL	30 Oct 90
		Edge - 1 ST	30 Oct 90
		Edge - 3 ST	30 Oct 90
		3 - 4 ST	30 Oct 90
C-3	SP/CW/HL/LI	Edge - 3 SL	30 Oct 90
		3 - 4 SL	30 Oct 90
		Edge - 1 ST	30 Oct 90
		Edge - 3 ST	30 Oct 90
		3 - 4 ST	30 Oct 90
C-6	SP/CW/HL/LI	Edge - 1 SL	30 Oct 90
A-5	B/CW/HL/LI	Edge - 1 SL	30 Oct 90
D-4	B/HL/MI	Edge - 3 SL	30 Oct 90
C-4	B/HL/MI	Edge - 3 ST	30 Oct 90
D-2	B/CW/HL/LI	Edge - 3 SL	1 Nov 90
		Edge - 1 LT	1 Nov 90
		3 - 4 ST	1 Nov 90
		Edge - 3 ST	1 Nov 90
A-6	B/CW/HL/LI	Edge - 3 SL	1 Nov 90
		Edge - 3 ST	1 Nov 90
D-6	SP/CW/HL/LI	Edge - 3 SL	1 Nov 90
		3 - 4 SL	1 Nov 90
		Edge - 1 SL	1 Nov 90
		Edge - 1 ST	1 Nov 90
		Edge - 3 ST	1 Nov 90
		3 - 4 ST	1 Nov 90
C-3	SP/CW/HL/LI	Edge - 3 SL	1 Nov 90
		3 - 4 SL	1 Nov 90
		Edge - 1 ST	1 Nov 90
		Edge - 3 ST	1 Nov 90
		3 - 4 ST	1 Nov 90
C-6	SP/CW/HL/LI	Edge - 1 SL	1 Nov 90
A-5	B/CW/HL/LI	Edge - 1 SL	1 Nov 90
D-4	B/HL/MI	Edge - 3 SL	1 Nov 90
C-4	B/HL/MI	Edge - 3 ST	1 Nov 90
A-4	SP/HL/MI	Edge - 3 SL	1 Nov 90

Additional Cracking as it Occurred

Specimen	I.D.	Location	Date
D-2	B/CW/HL/LI	1 - 2 ST	2 Nov 90
		Edge (PC) - 1 ST	
A-2	B/HL/MI	Edge - 1 SL	5 Nov 90
		(SC) 1 - 2 ST	
D-4	B/HL/MI	Various Surface Cracks	7 Nov 90
C-4	B/HL/MI	Edge - 3 SL	7 Nov 90
A-2	B/HL/MI	Various Surface Cracks	7 Nov 90
A-6	B/CW/HL/LI	Edge (PC) - 1 ST	9 Nov 90
A-5	B/CW/HL/LI	(SC) 1 - 2 SL	9 Nov 90
		(SC) 3 - 4 SL	9 Nov 90
D-4	B/HL/MI	Edge (PC) - 1 SL	9 Nov 90
		(SC) 1 - 2 ST	9 Nov 90
		(SC) 3 - 4 ST	9 Nov 90
C-4	B/HL/MI	Edge - 1 SL	9 Nov 90
		(SC) 1 - 2 SL	9 Nov 90
		(SC) 3 - 4 SL	9 Nov 90
		(SC) 1 - 2 ST	9 Nov 90
		(SC) 3 - 4 ST	9 Nov 90
		Edge (PC) - 1 ST	9 Nov 90
B-5	B/HL/TF	(SC) 1 - 2 SL	9 Nov 90
		Edge (PC) - 1 SL	9 Nov 90
A-2	B/HL/MI	Edge - 1 SL	9 Nov 90
		Edge (PC) - 1 ST	9 Nov 90
		(SC) 1 - 2 ST	9 Nov 90
A-6	B/CW/HL/LI	Edge - 1 ST	13 Nov 90
A-5	B/CW/HL/LI	(SC) 1 - 2 ST	13 Nov 90
A-4	SP/HL/MI	Edge - 1 SL	13 Nov 90
A-1	SP/TL/SI	FCD	13 Nov 90
C-6	SP/CW/HL/LI	Edge - 3 ST	16 Nov 90
A-2	B/HL/MI	(SC) 1 - 2 SL	16 Nov 90
B-6	B/TL/SI	FCD	16 Nov 90
B-1	SP/TL/SI	FCD	16 Nov 90
D-1	B/TL/SI	FCD	16 Nov 90
Misc		Pitting Attack	19 Nov 90
D-2	B/CW/HL/LI	Edge - 1 SL	21 Nov 90
A-5	B/CW/HL/LI	1 - 2 ST	21 Nov 90
D-4	B/HL/MI	(SC) 1 - 2 SL	21 Nov 90
		(SC) 3 - 4 SL	21 Nov 90
A-2	B/HL/MI	(SC) 1 - 2 SL	21 Nov 90
B-2	B/TL/SI	FCD	21 Nov 90
B-3	SP/HL/MI	Edge - 3 ST	21 Nov 90
A-3	SP/TL/SI	FCD	21 Nov 90

B-2	B/TL/SI	Edge (PC) - 3 ST	23 Nov 90
D-2	B/CW/HL/LI	Edge (PC) - 1 ST	23 Nov 90
A-2	B/HL/MI	Edge (PC) - 3 ST	23 Nov 90
		Edge (PC) - 1 ST	23 Nov 90

Test Terminated
Results (Full Cracks)

D-2	(B/CW/HL/LI)	Edge - 1 SL	27 Nov 90
		Edge - 3 SL[1]	27 Nov 90
		Edge - 1 ST	27 Nov 90
		Edge - 3 ST	27 Nov 90
		1 - 2 ST	27 Nov 90
		3 - 4 ST	27 Nov 90
		Edge - 1 LT[1]	27 Nov 90
A-6	(B/CW/HL/LI)	Edge - 3 SL[1]	27 Nov 90
		Edge - 1 ST	27 Nov 90
		Edge - 3 ST	27 Nov 90
D-6	(SP/CW/HL/LI)	Edge - 1 SL	27 Nov 90
		Edge - 3 SL[1]	27 Nov 90
		3 - 4 SL	27 Nov 90
		Edge - 1 ST	27 Nov 90
		Edge - 3 ST	27 Nov 90
		3 - 4 ST	27 Nov 90
C-3	(SP/CW/HL/LI)	Edge - 1 SL	27 Nov 90
		Edge - 3 SL[1]	27 Nov 90
		3 - 4 SL	27 Nov 90
		Edge - 1 ST	27 Nov 90
		Edge - 3 ST	27 Nov 90
		3 - 4 ST	27 Nov 90
C-6	(SP/CW/HL/LI)	Edge - 1 SL[1]	27 Nov 90
		Edge - 3 ST	27 Nov 90
A-5	(B/CW/HL/LI)	Edge - 1 SL	27 Nov 90
		1 - 2 ST	27 Nov 90
D-4	(B/HL/MI)	Edge - 3 SL	27 Nov 90
C-4	(B/HL/MI)	Edge - 3 ST	27 Nov 90
		Edge - 3 SL	27 Nov 90
		Edge - 1 SL	27 Nov 90
		Edge - 1 ST	27 Nov 90
		3 - 4 SL	27 Nov 90
A- 4	(SP/HL/MI)	Edge - 3 SL	27 Nov 90
		Edge - 1 SL	27 Nov 90
		3 - 4 SL	27 Nov 90
A-2	(B/HL/MI)	Edge - 1 SL	27 Nov 90
B-3	(SP/HL/MI)	Edge - 3 ST	27 Nov 90
B-5	(B/HL/TF)	Minor Surface Cracks	27 Nov 90
B-2	(B/TL/SI)	Minor Surface Cracks	27 Nov 90
D-5	(SP/HL/MI)	Excellent Condition	27 Nov 90
C-5	(B/HL/TF)	Excellent Condition	27 Nov 90
C-1	(B/HL/TF)	Excellent Condition	27 Nov 90
D-1	(B/TL/SI)	Excellent Condition	27 Nov 90

B-6	(B/TL/SI)	Excellent Condition	27 Nov 90
A-3	(SP/TL/SI)	Excellent Condition	27 Nov 90
A-1	(SP/TL/SI)	Excellent Condition	27 Nov 90
B-1	(SP/TL/SI)	Excellent Condition	27 Nov 90
B-4	(SP/HL/TF)	Excellent Condition	27 Nov 90
D-3	(SP/HL/TF)	Excellent Condition	27 Nov 90
C-2	(SP/HL/TF)	Excellent Condition	27 Nov 90

1 Cracks present at test start

B Bare Condition
SP Shot Peended Surface
TL Taper Lok Fastener
HL Hi Lite Fastener
TF Transition Fit
SI Standard Interference
LI Low Interference
FCD Fastener Cadmium Depletion

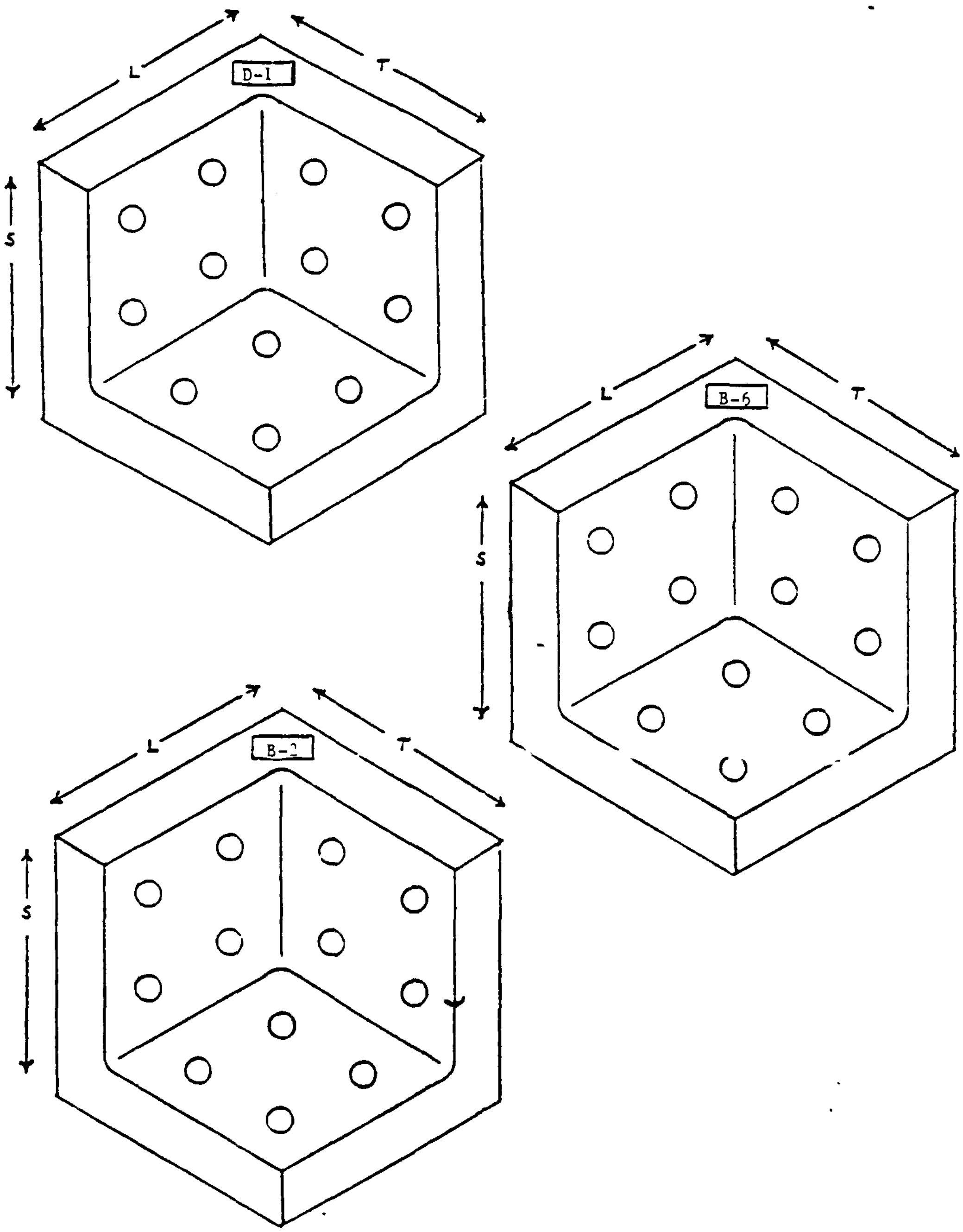


Fig B-1. Bare/Taper-Lok/Standard Int Fit

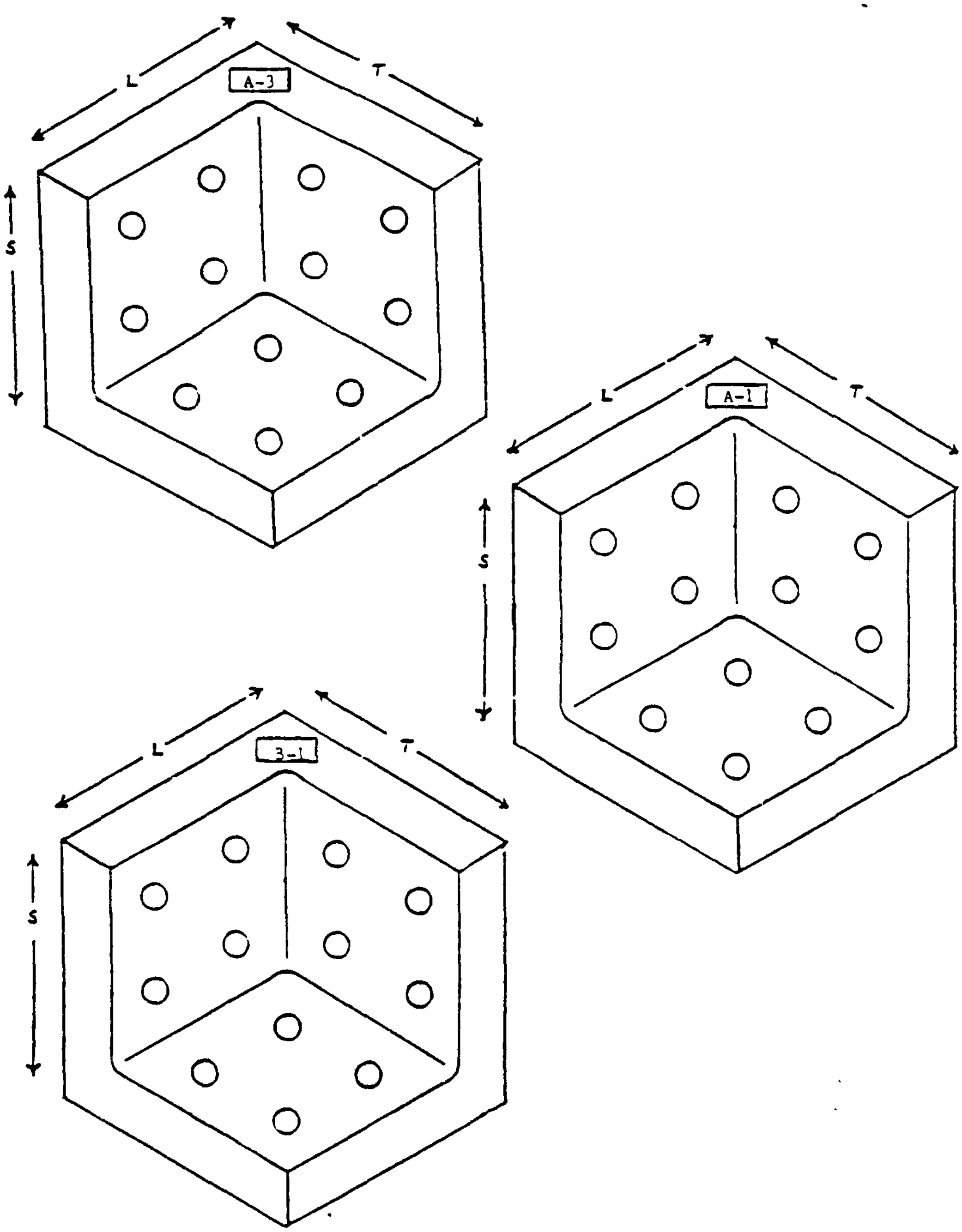


Fig B-2. Shot Peened/Taper-Lok/Standard Int Fit

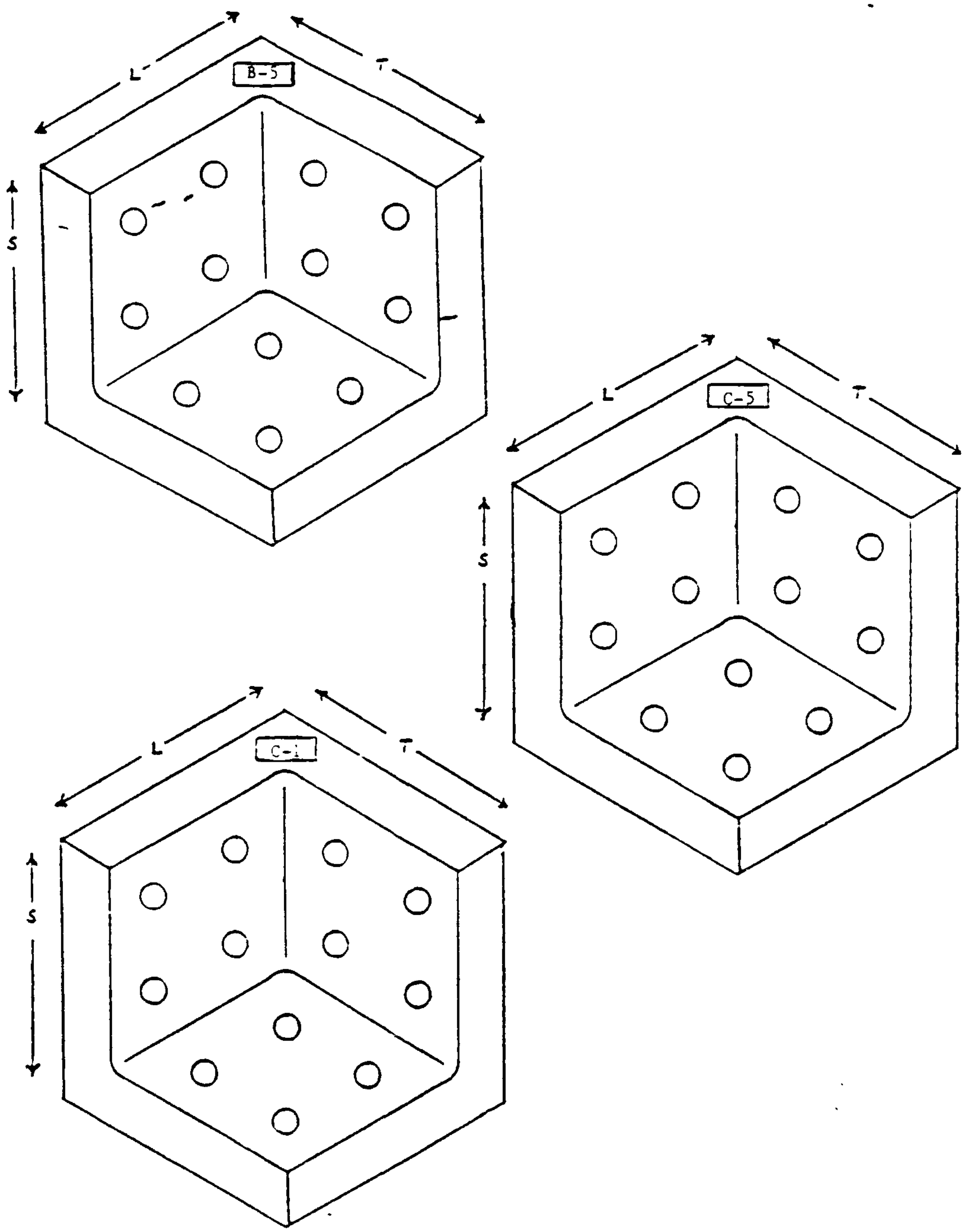


Fig B-3. Bare/Hi-Lite/Transition Fit

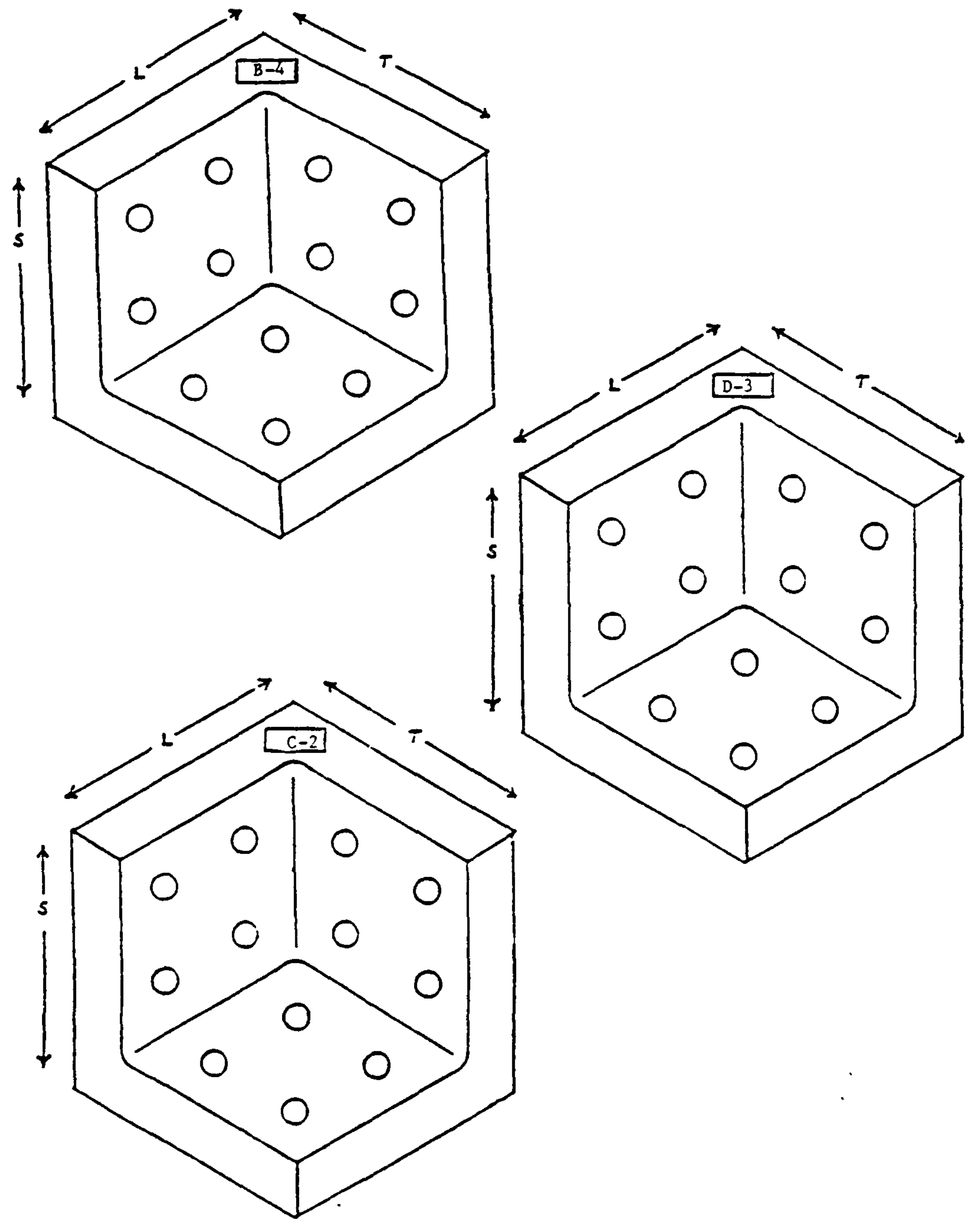


Fig B-4. Shot Peened/Hi-Lite/Transition Fit

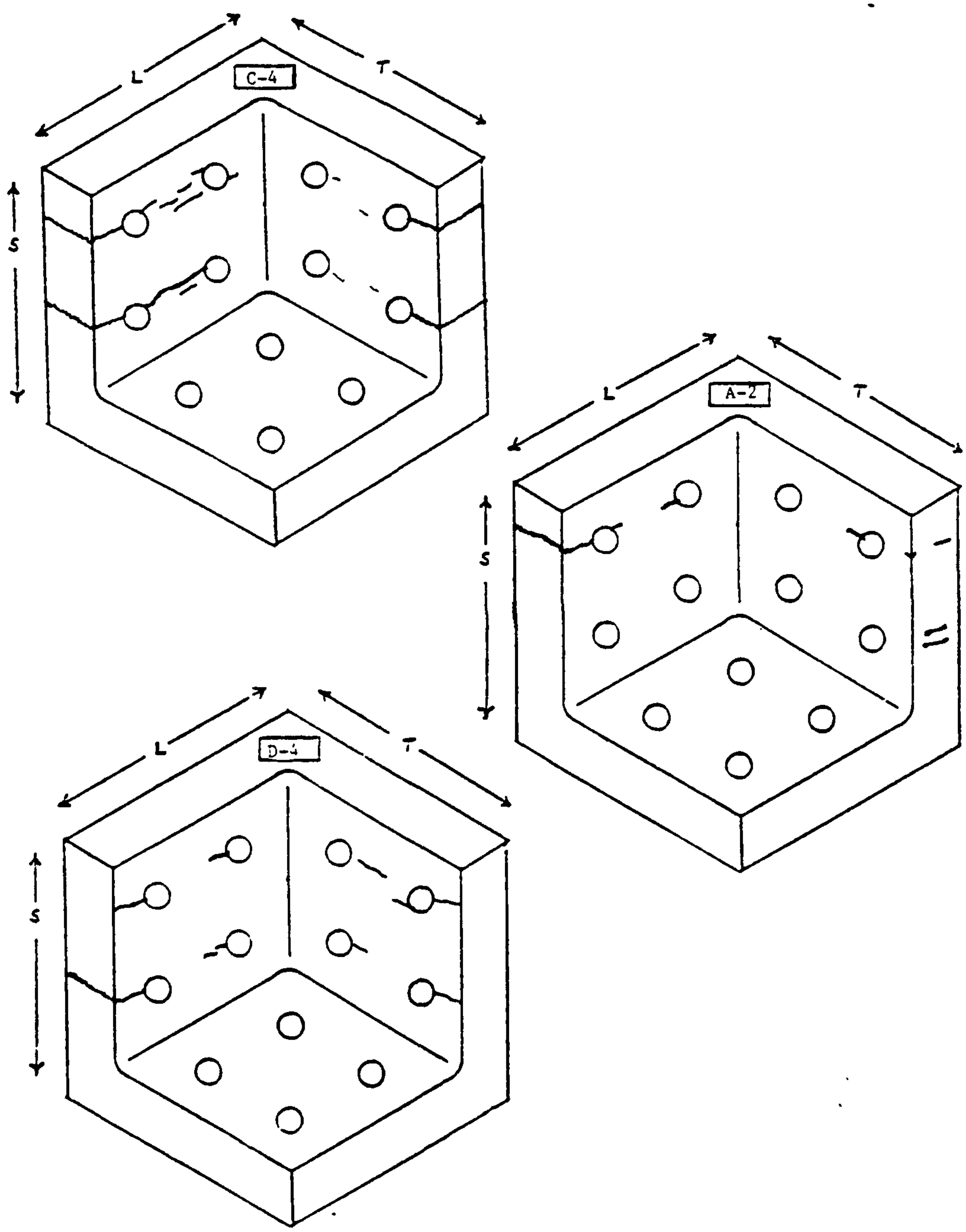


Fig B-5. Bare/Hi-Lite/Moderate Int Fit

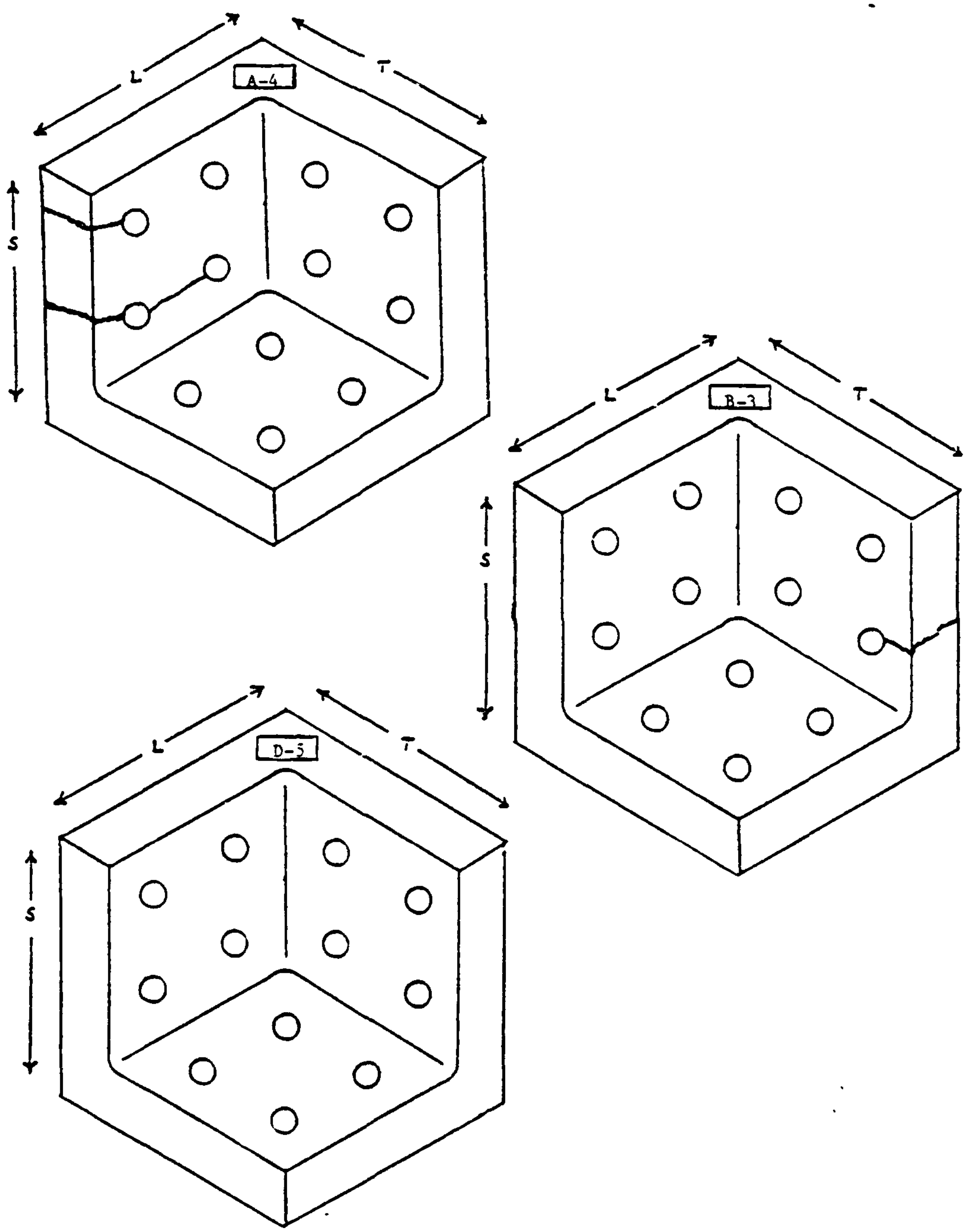


Fig B-6. Shot Peened/Hi-Lite/Moderate Int Fit

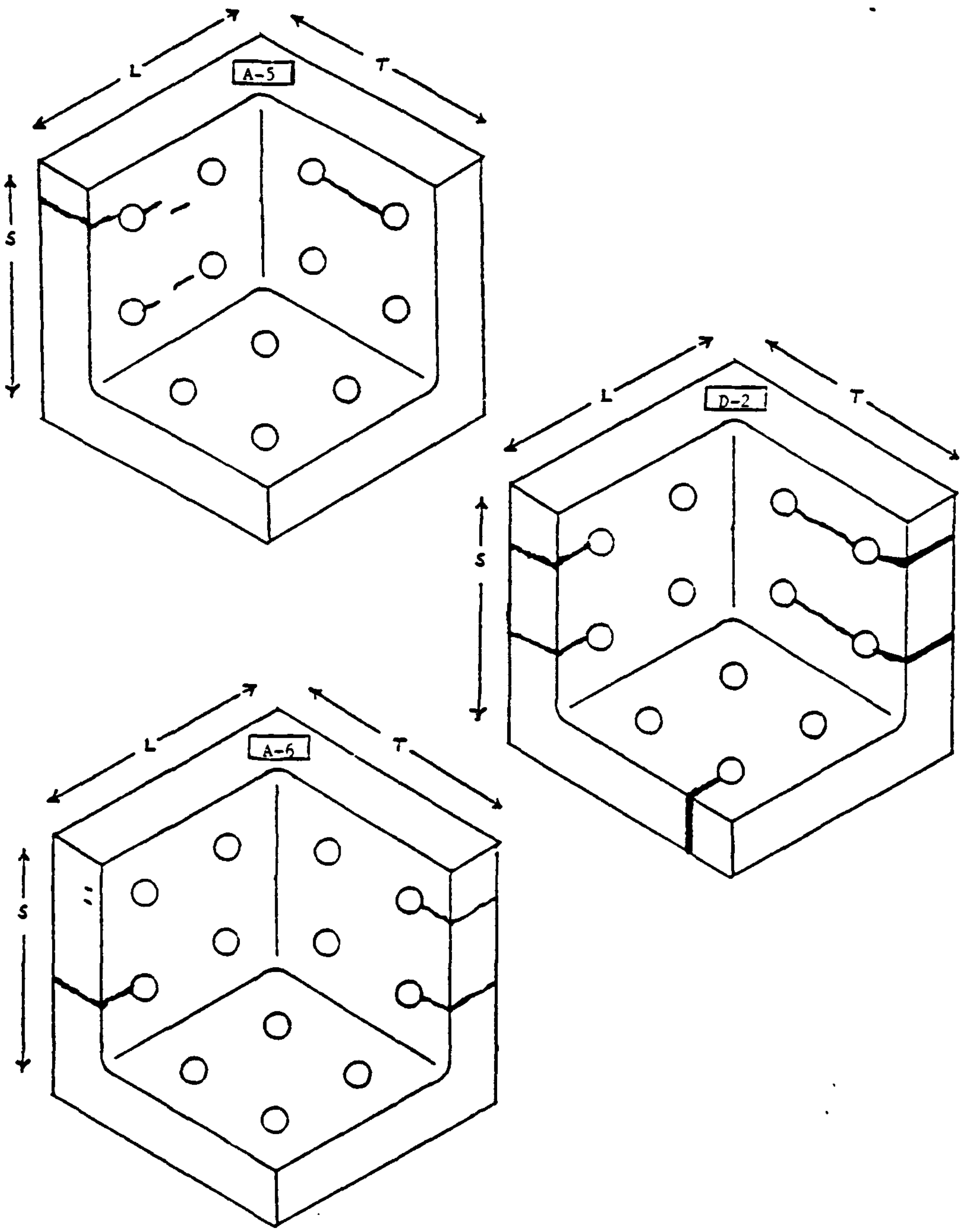


Fig B-7. Bare/Cold Work/Hi-Lite/Low Int Fit

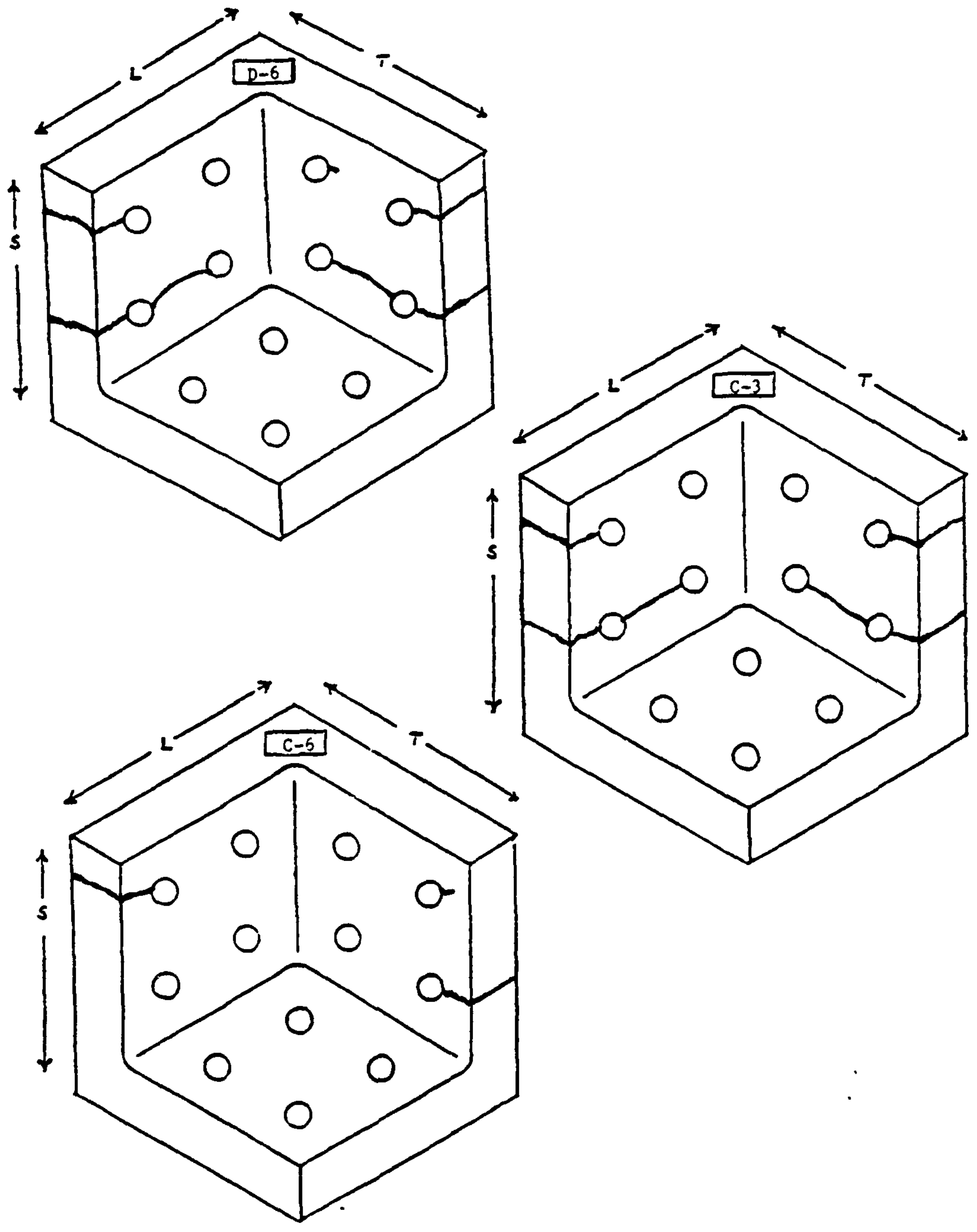


Fig B-8. Shot Peened/Cold Work/Hi-Lite Low Int Fit

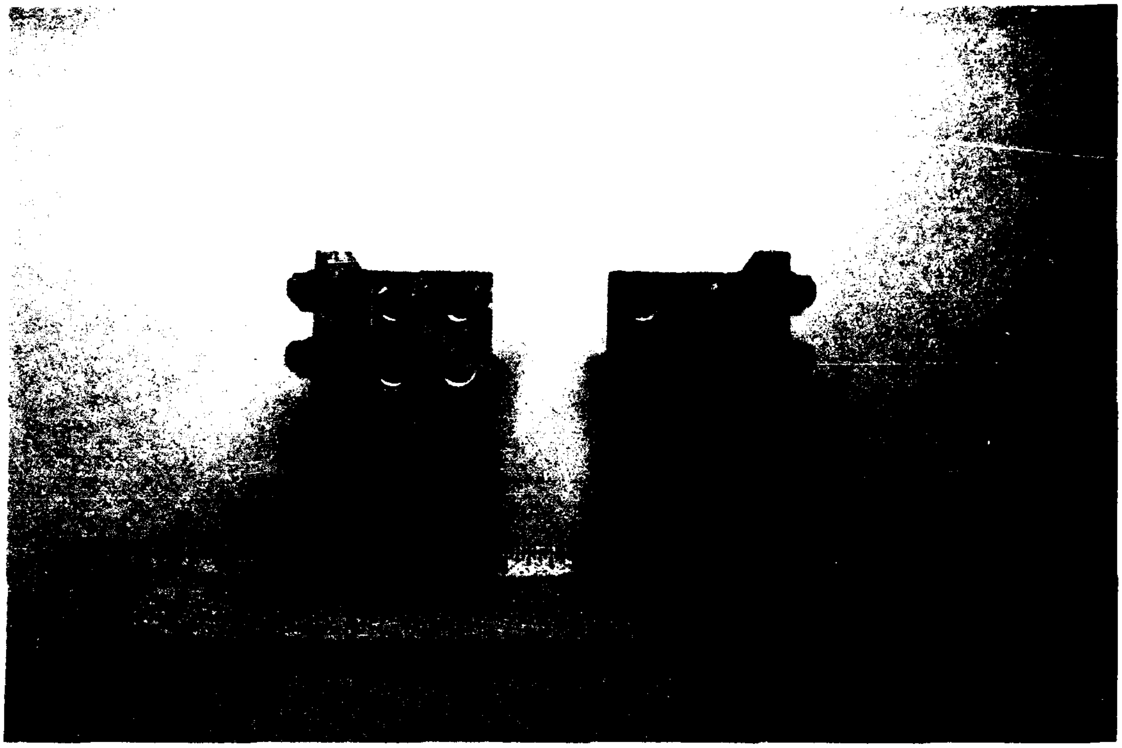


Fig B-9. Hi-Lite Fastener System (Transition Fit)

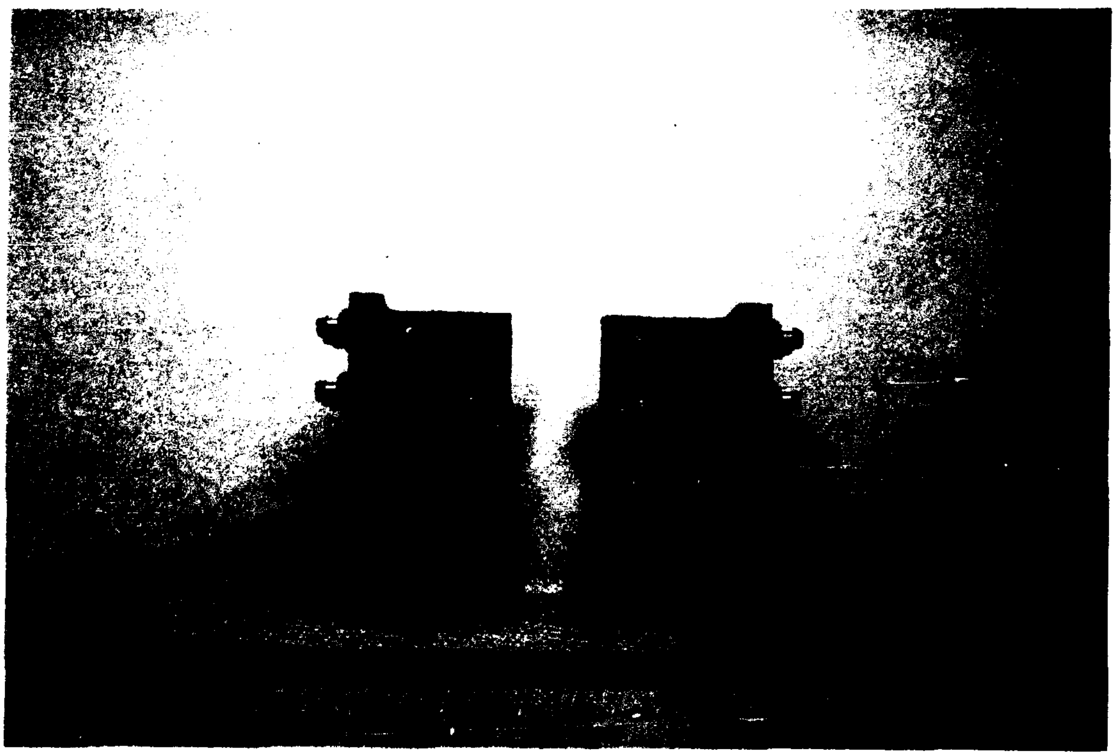


Fig B-10. Taper-Lok Fastener System (Standard Int Fit)

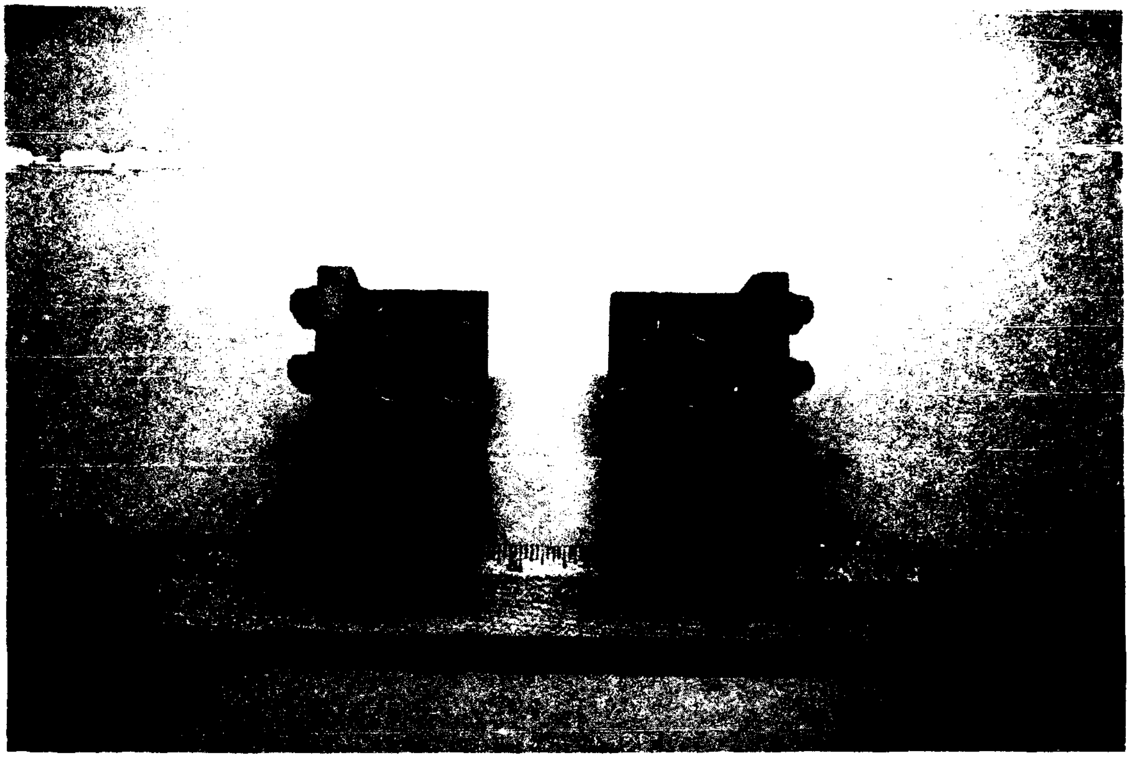


Fig B-11. Hi-Lite Fastener System (Moderate Int Fit)

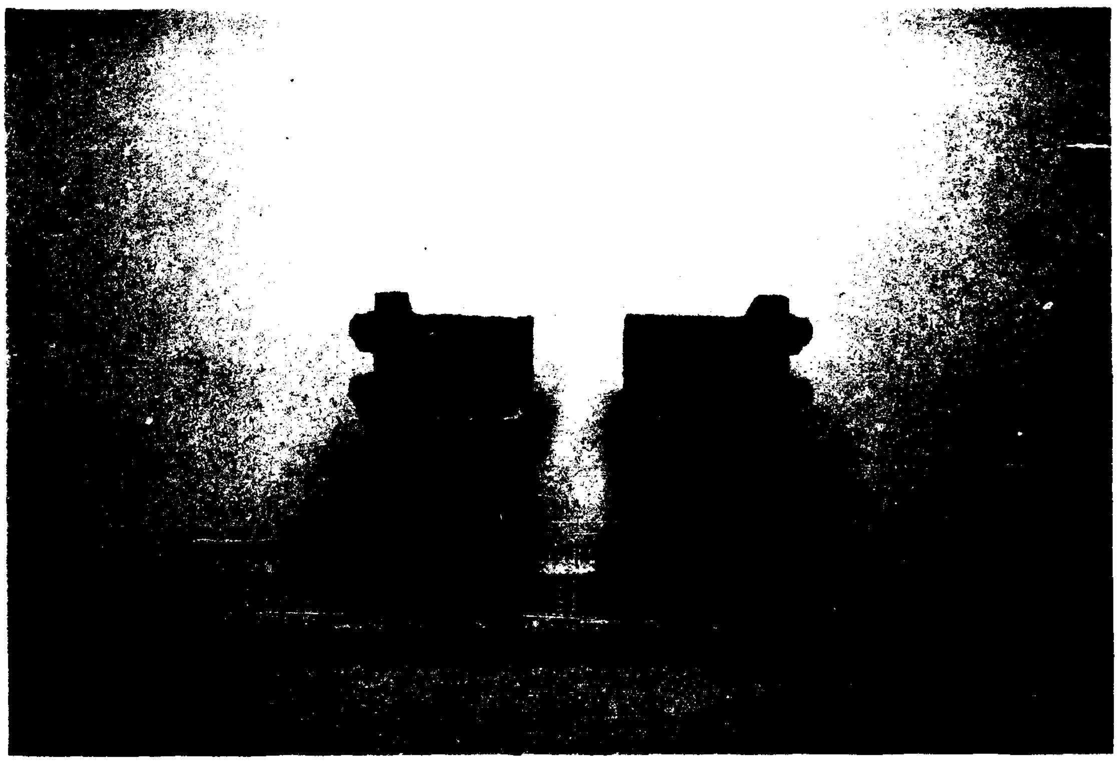


Fig B-12. Cold Work/Hi-Lite Fastener Systems (Low Int Fit)

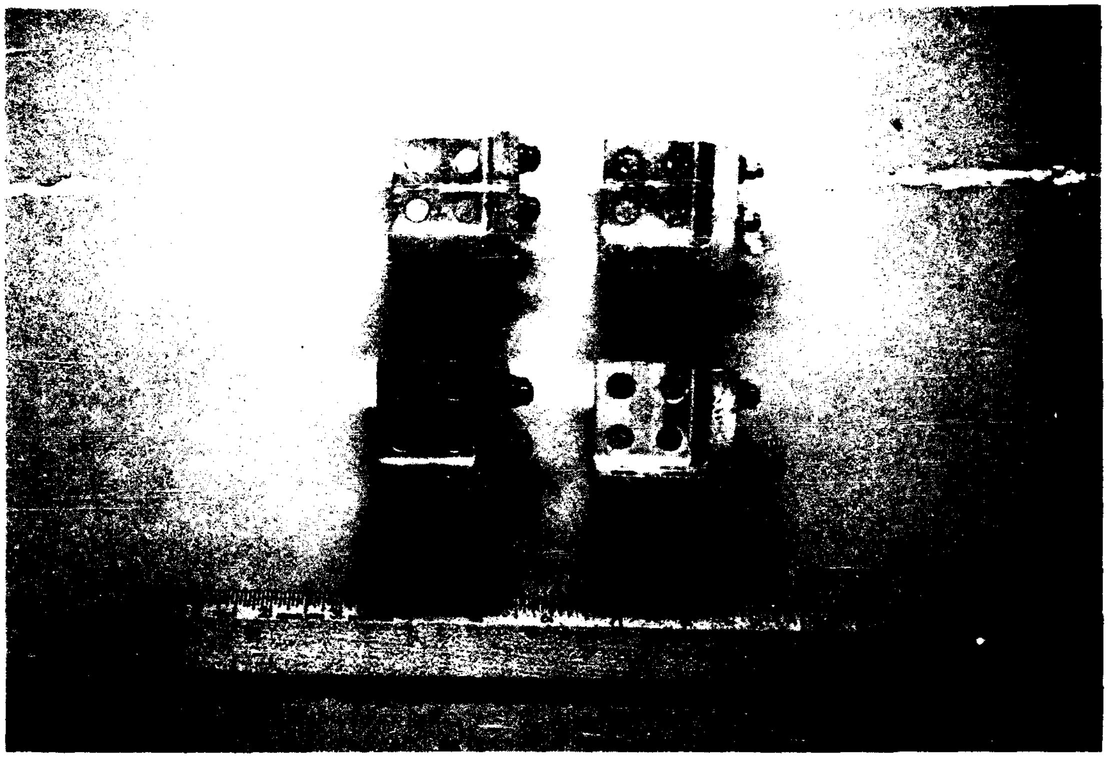


Fig B-13. Representative Group (Bare Condition)

Fig B-14. Representative Group (Shot Peened Condition)

Appendix C

Hole Parameters and Levels of Interference for Fatigue Coupons

Open Hole Coupons [1]

Protruding Head Style		Flush[2] Head Style	
8090-	24	8090-	18
	27		19
	28		29
	15		17
	23		N/A
2090-	16	2090-	5
	1		3
	17		2
	20		19
	18		4
2024-	17	2024-	34
	21		18
	15		35
	20		19
	16		36

[1] Mean Hole Diameter .250" - .260"

[2] Countersunk for 1/4 inch Hi-Shear Fastener

Clearance and Transition Fit [3], Hi-Shear "Hi-Lite ST"

Protruding Head			Flush Head		
N/A			8090-	16	-(.0015)
N/A				14	N/A
N/A				6	-(.0020)
N/A				13	-(.0020)
N/A			8090-	1	-(.0003)
N/A				2	(.0000)
N/A				3	-(.0003)
N/A				4	-(.0008)
2090-	7	-(.0035)	2090-	37	-(.0015)
	42	-(.0020)		32	-(.0025)
	15	-(.0020)		31	-(.0020)
	41	-(.0020)		30	-(.0020)

Protruding Head		Flush Head	
2090- 39	(.0000)	2090- 35	-(.0005)
40	-(.0005)	33	(.0000)
14	-(.0005)	36	(.0000)
38	(.0000)	34	-(.0010)
2024- 28	-(.0020)	2024- 23	-(.0020)
24	-(.0015)	22	-(.0020)
27	-(.0020)	37	-(.0020)
26	-(.0020)	25	-(.0020)
2024- 10	(.0017)	2024- 41	(.0006)
12	(.0016)	13	(.0007)
11	(.0017)	39	(.0008)
9	(.0017)	14	(.0008)

[3] (Pin Diameter - Hole Diameter), Positive quantities measure levels of interference, negative quatities detail clearance.

Interference Fit [4], Deutsh "Taper-Lok"

Protruding Head		Flush Head	
N/A		8090- 20	(.0012)
N/A		12	(.0012)
N/A		21	(.0018)
N/A		22	(.0018)
2090- 8	(.0025)	2090- 24	(.0026)
25	(.0031)	21	(.0023)
6	(.0027)	9	(.0021)
10	(.0024)	22	(.0021)
2024- 30	(.0028)	2024- 42	(.0031)
32	(.0027)	31	(.0034)
40	(.0030)	38	(.0031)
29	(.0026)	33	(.0033)

[4] Positive levels of interference fit converted from head protrusion measurements.

Cold Work using Split Sleeve Expansion [5], Fatigue Technology

Protruding Head			Flush Head		
8090-	7	(3.48)	8090-	25	(3.18)
	9	(3.40)		11	(3.05)
	8	(3.48)		5	(3.10)
N/A				10	(2.97)
2090-	28	(2.92)	2090-	13	(3.27)
	26	(2.48)		29	(2.07)
	27	(2.36)		12	(3.35)
N/A				11	(3.35)
2024-	6	(2.27)	2024-	2	(2.60)
	8	(2.64)		1	(2.56)
	5	(2.72)		4	(2.43)
	7	(2.51)		3	(2.04)

[5] Percent cold expansion (Final Hole Size - Original Hole Size) ÷ Original Hole Size

Interference Fit in Cold Worked Holes [6], Hi-Shear "Hi-Lite ST"

Protruding Head			Flush Head		
8090-	7	(.0022)	8090-	25	(.0024)
	9	(.0024)		11	(.0027)
	8	(.0022)		5	(.0026)
N/A				10	(.0029)
2090-	28	(.0020)	2090-	13	(.0027)
	26	(.0010)		29	(.0020)
	27	(.0018)		12	(.0025)
N/A				11	(.0025)
2024-	6	(.0035)	2024-	2	(.0043)
	8	(.0037)		1	(.0044)
	5	(.0035)		4	(.0042)
	7	(.0040)		3	(.0041)

[6] Positive levels of interference fit, (Pin diameter - Final Hole Size)

Appendix D

Fatigue Test Results

SPECIMEN NUMBER	M. STRESS (ksi)	CYCLES TO FAILURE		
8090-24	30	18779	(Open Hole/No Pin/Protruding Head Style)	
8090-27	30	15252		
8090-28	30	17232	Avg = 16,722	Std Dev = 1,979
8090-15	30	18224		
8090-23	30	14124		
8090-7	30	279888	(Prot Head/Cold Work/Hi-Lite ST/Std Int Fit)	
8090-9	30	217256		
8090-8	30	330051	Avg = 275,732	Std Dev = 56,512
8090-18	30	16244	(Open Hole/No Pin/Flush Head Style)	
8090-19	30	13859		
8090-29	30	18553	Avg = 15,543	Std Dev = 2,346
8090-17	30	13514		
8090-16	30	21330	(Flush Head/Hi-Lite ST/Clearance Fit)	
8090-14	30	33469		
8090-6	30	24774	Avg = 27,313	Std Dev = 5,346
8090-13	30	29677		
8090-20	30	41819	(Flush Head/Taper-Lok/Low Int Fit)	
8090-12	30	146484		
8090-21	30	187781	Avg = 141,881	Std Dev = 69,753
8090-22	30	191440		
8090-1	30	20828	(Flush Head/Hi-Lite ST/Transition Fit)	
8090-2	30	25056		
8090-3	30	22985	Avg = 22,566	Std Dev = 1,895
8090-4	30	21394		
8090-25	30	169188	(Flush Head/Cold Work/Hi-Lite ST/Std Int Fit)	
8090-11	30	293105		
8090-5	30	294423	Avg = 262,471	Std Dev = 62,192
8090-10	30	293169		
2090-16	30	5393	(Open Hole/No Pin/Protruding Head Style)	
2090-1	30	20309		
2090-17	30	18077	Avg = 17,222	Std Dev = 7,195
2090-20	30	24757		
2090-18	30	17577		
2090-7	30	87058	(Prot Head/Hi-Lite ST/Clearance Fit)	
2090-42	30	66197		
2090-15	30	44246	Avg = 66,939	Std Dev = 17,619
2090-41	30	70256		
2090-8	30	517212	(Prot Head/Taper-Lok/Std Int Fit)	
2090-25	30	486912		
2090-6 *	30	363168	Avg = 461,962	Std Dev = 67,777
2090-10	30	480554		
2090-39	30	52174	(Prot Head/Hi-Lite ST/Transition Fit)	
2090-40	30	56872		
2090-14	30	55158	Avg = 54,769	Std Dev = 1,942
2090-38	30	54873		

2090-28*	30	1020590	(Prot Head/Cold Work/Hi-Lite ST/Std Int Fit)
2090-26	30	443105	
2090-27*	30	977048	Avg = 813,581 Std Dev = 321,579
2090-5	30	15908	(Open Hole/No Pin/Flush Head Style)
2090-3	30	19378	
2090-2	30	18535	Avg = 18,775 Std Dev = 1,756
2090-19	30	20559	
2090-4	30	19493	
2090-37	30	44242	(Flush Head/Hi-Lite ST/Clearance Fit)
2090-32	30	56903	
2090-31	30	40104	Avg = 46,977 Std Dev = 7,149
2090-30	30	46658	
2090-24*	30	478394	(Flush Head/Taper-Lok/Std Int Fit)
2090-21	30	464999	
2090-9 **	30	69372	Agv = 405,928 Std Dev = 114,111
2090-22	30	274392	
2090-35	30	56247	(Flush Head/Hi-Lite ST/Transition Fit)
2090-33	30	45402	
2090-36	30	66363	Avg = 54,395 Std Dev = 9,144
2090-34	30	49567	
2090-13*	30	805861	(Flush Head/Cold Work/Hi-Lite ST/Std Int Fit)
2090-29*	30	435568	
2090-12*	30	514090	Avg = 726,770 Std Dev = 324,927
2090-11*	30	1151560	
2024-17	30	12916	(Open Hole/No Pin/Protruding Head Style)
2024-21	30	12533	
2024-15	30	11789	Avg = 12,420 Std Dev = 423
2024-20	30	12259	
2024-16	30	12605	
2024-28	30	28833	(Prot Head/Hi-Lite ST/Clearance Fit)
2024-24	30	26440	
2024-27	30	21570	Avg = 24,741 Std Dev = 3,491
2024-26	30	22119	
2024-30*	30	193560	(Prot Head/Taper-Lok/Std Int Fit)
2024-32*	30	249569	
2024-40*	30	391302	Avg = 229,203 Std Dev = 128,476
2024-29*	30	82380	
2024-10	30	139509	(Prot Head/Hi-Lite ST/Low Int Fit)
2024-12	30	70762	
2024-11	30	75873	Avg = 90,842 Std Dev = 32,564
2024-9	30	77223	
2024-6 *	30	242228	(Prot Head/Cold Work/Hi-Lite ST/Mod Int Fit)
2024-8 *	30	162229	
2024-5	30	133378	Avg = 179,278 Std Dev = 56,392

2024-34	30	11006	(Open Hole/No Pin/Flush Head Style)
2024-18	30	12011	
2024-35	30	10879	Avg = 11,689 Std Dev = 769
2024-19	30	12751	
2024-36	30	11799	
2024-23	30	18689	(Flush Head/Hi-Lite ST/Clearance Fit)
2024-22	30	17331	
2024-37	30	19235	Avg = 19,384 Std Dev = 2,090
2024-25	30	22280	
2024-42	30	148233	(Flush Head/Taper-Lok/Std Int Fit)
2024-31	30	230704	
2024-38	30	198861	Avg = 192,599 Std Dev = 41,591
2024-33**	30	181051	
2024-41	30	53682	(Flush Head/Hi-Lite ST/Transition Fit)
2024-13	30	41580	
2024-39	30	57651	Avg = 51,168 Std Dev = 6,847
2024-14	30	51758	
2024-2	30	90511	(Flush Head/Cold Work/Hi-Lite ST/Mod Int Fit)
2024-1 *	30	203583	
2024-4	30	153209	Avg = 164,256 Std Dev = 55,300
2024-3 *	30	209722	

* Specimen failed away from hole and was regripped/retested.

** Specimen failed away from hole but could not be regripped/retested. Not included in calculations for average lifetimes.

FATIGUE TEST COUPONS

Explanation for Codes Used

C	Countersunk Hole (No Pin)
F	Flush Head Style
P	Protruding Head Style
O	Open Hole (No Pin)
TL	Taper Lok Fastening System
HL	Hi Lite Fastening System
CW	Cold Work of Hole Through Thickness
Clr	Clearance Fit
Tra	Transition Fit
Low	Low Interference Fit
Std	Standard Interference Fit
Mod	Moderate Interference Fit
Clr	(oversize hole)
Tra	(oversize hole) to .0010 inch
Low	.0010 to .0025 inches
Std	.0010 to .0035 inches
Mod	.0035 to .0050 inches
CW	2.0 to 3.5 % expansion

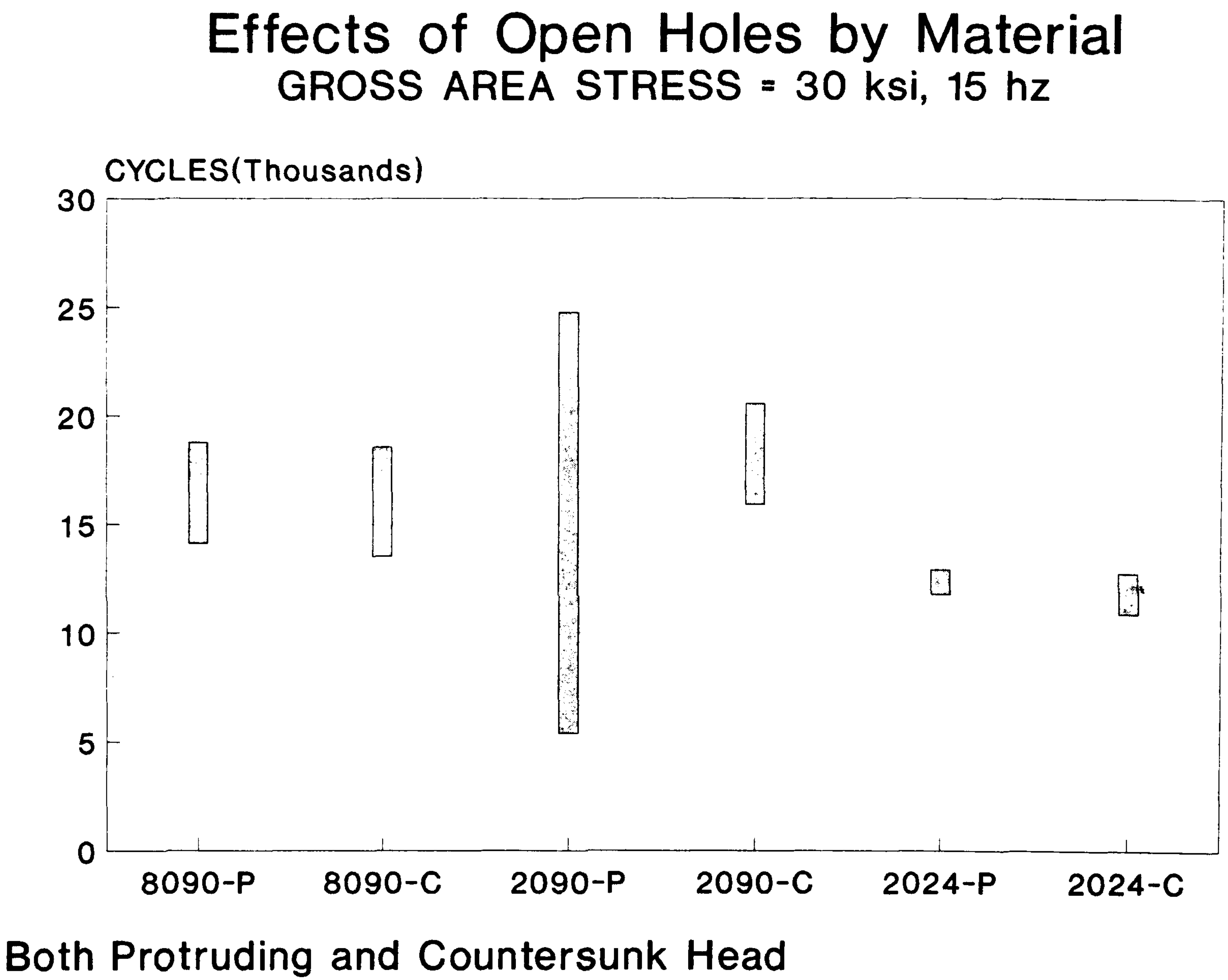
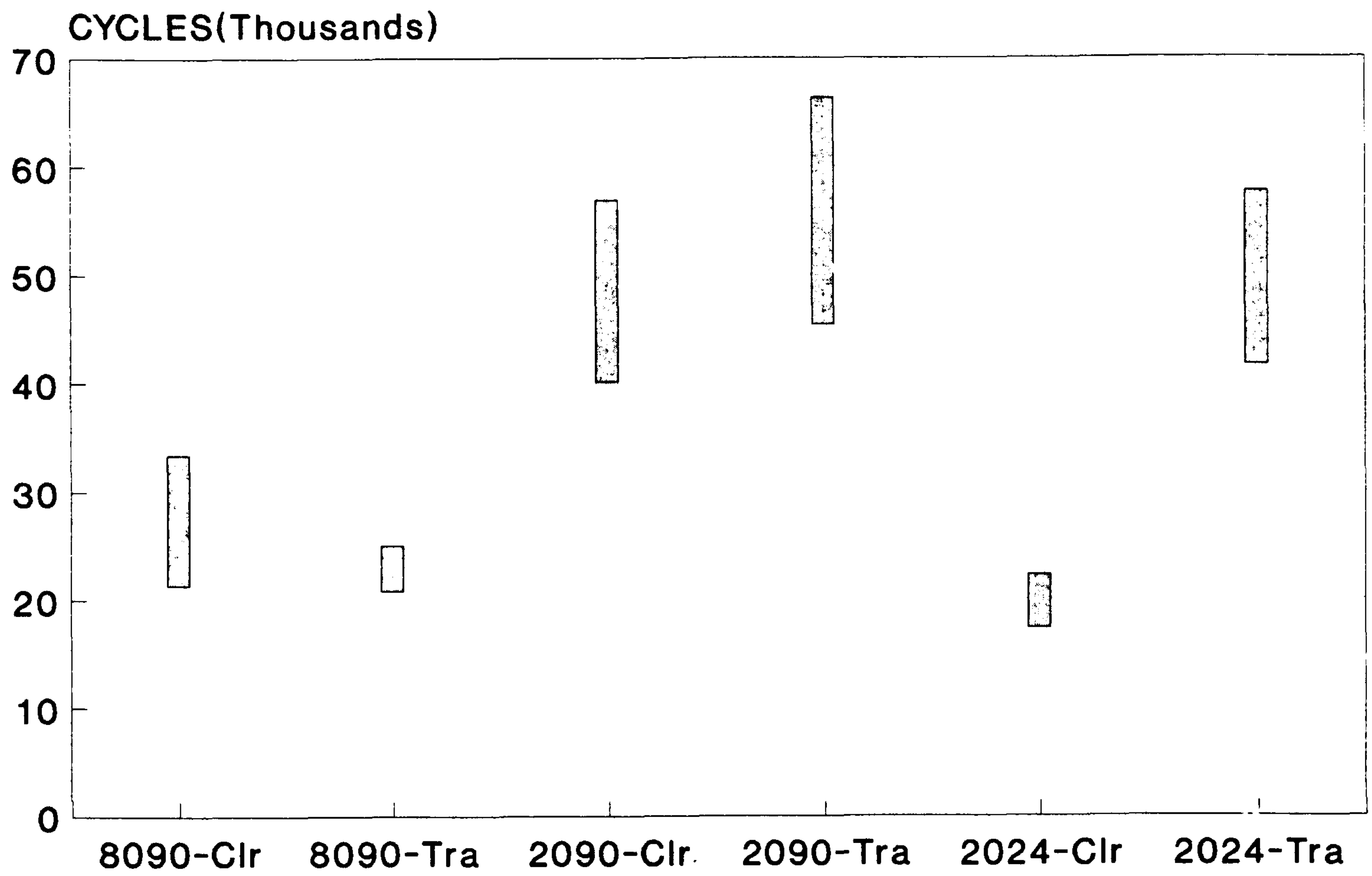


Fig D-1. Effects of Open Holes by Material

Comparison of Hi-Lite ST 8090,2090,2024

GROSS AREA STRESS = 30 ksi, 15 hz



Flush Head Style

Fig D-2. Comparison of Hi-Lite ST 8090,2090,2024

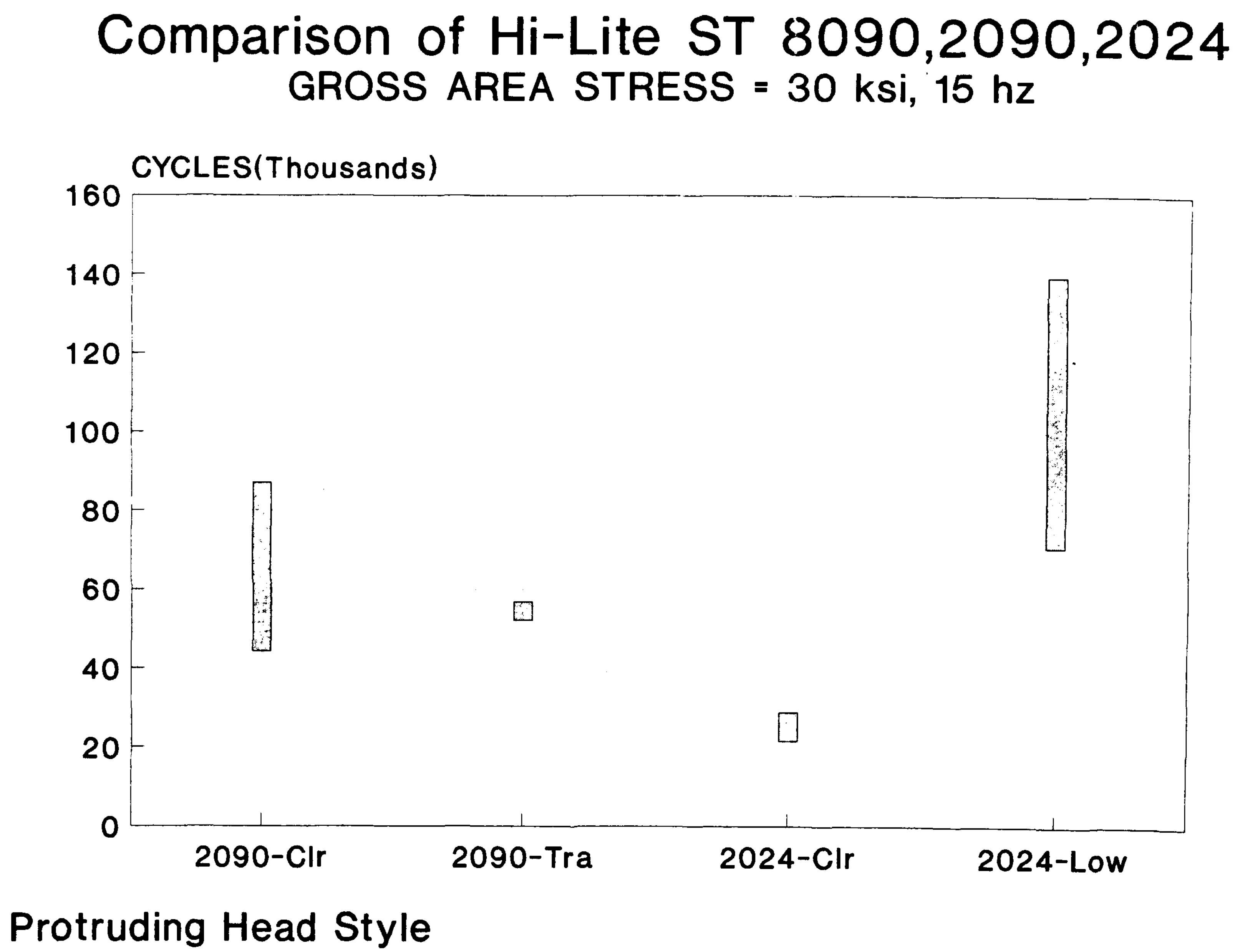


Fig D-3. Comparison of Hi-Lite ST 8090,2090,2024

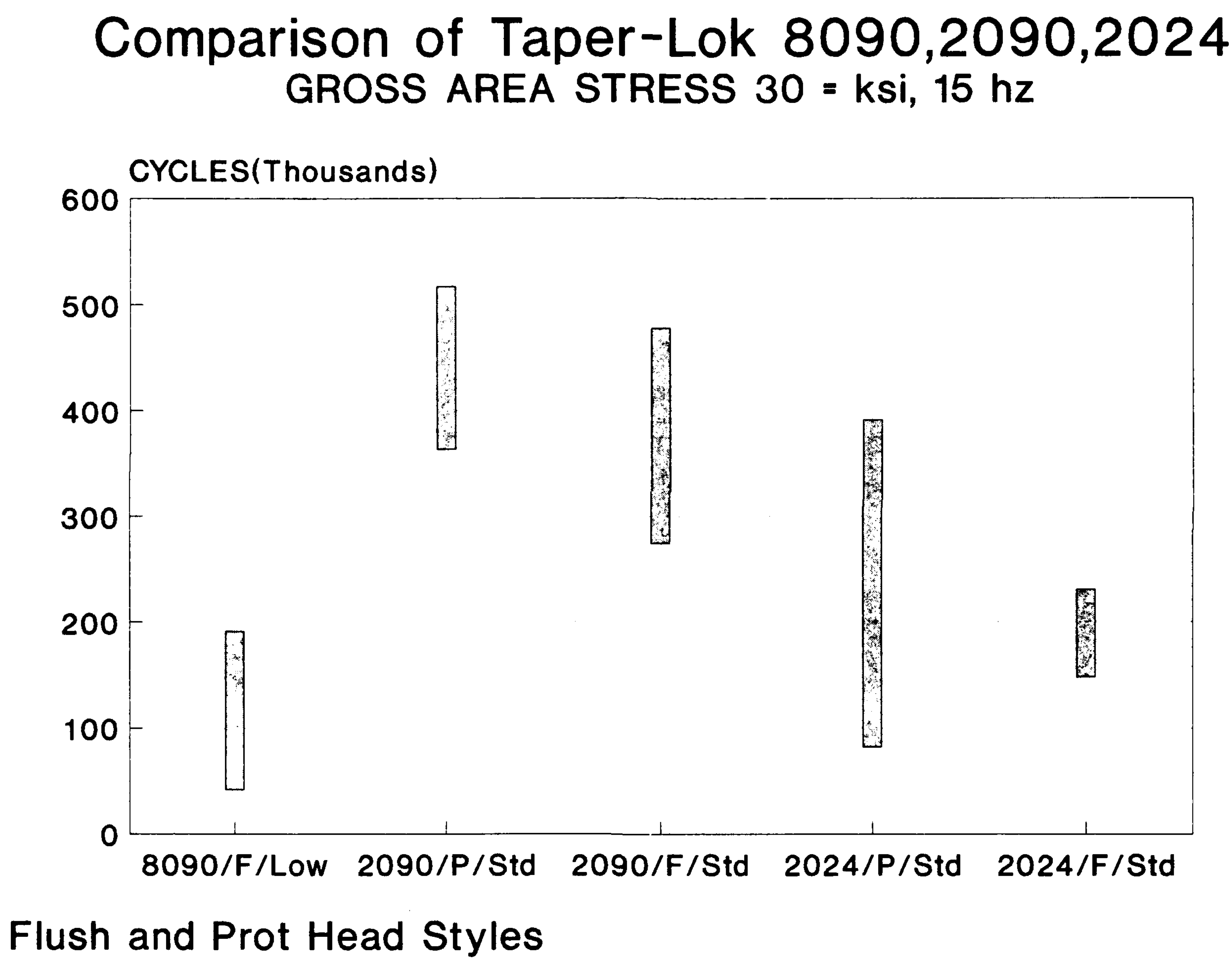


Fig D-4. Comparison of Taper-Lok 8090,2090,2024

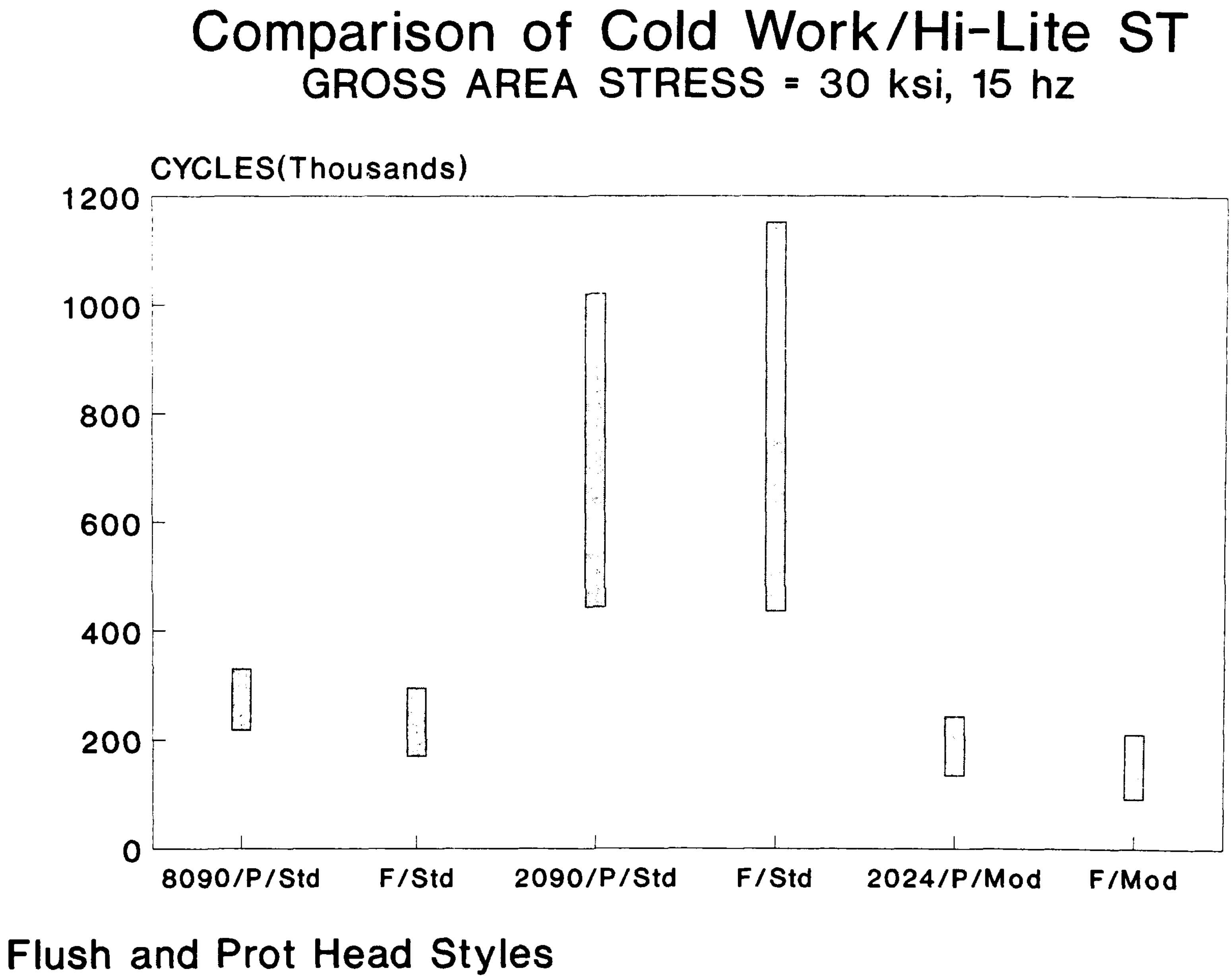


Fig D-5. Comparison of Cold Work/Hi-Lite ST

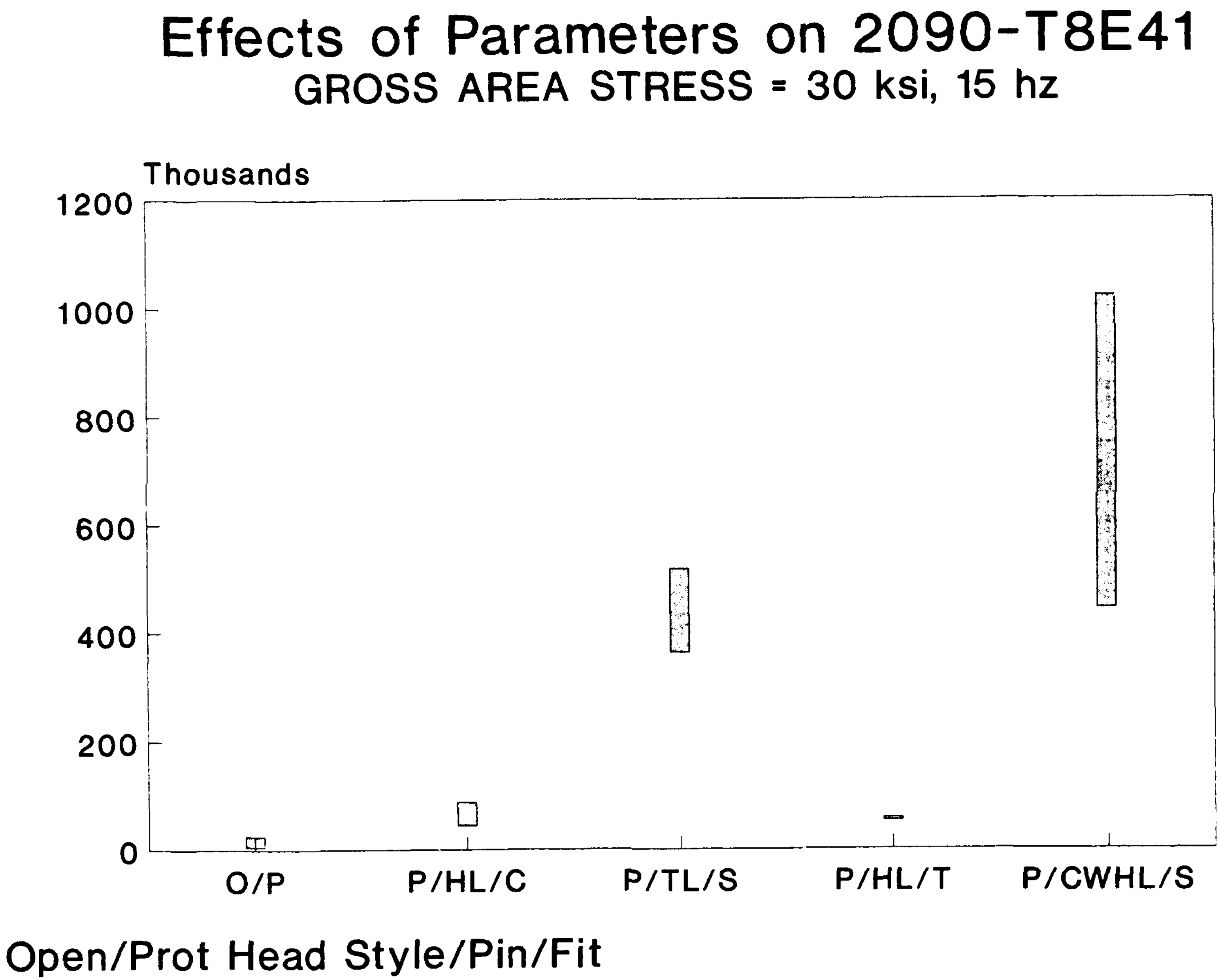


Fig D-6. Effects of Parameters on 2090-T8E41

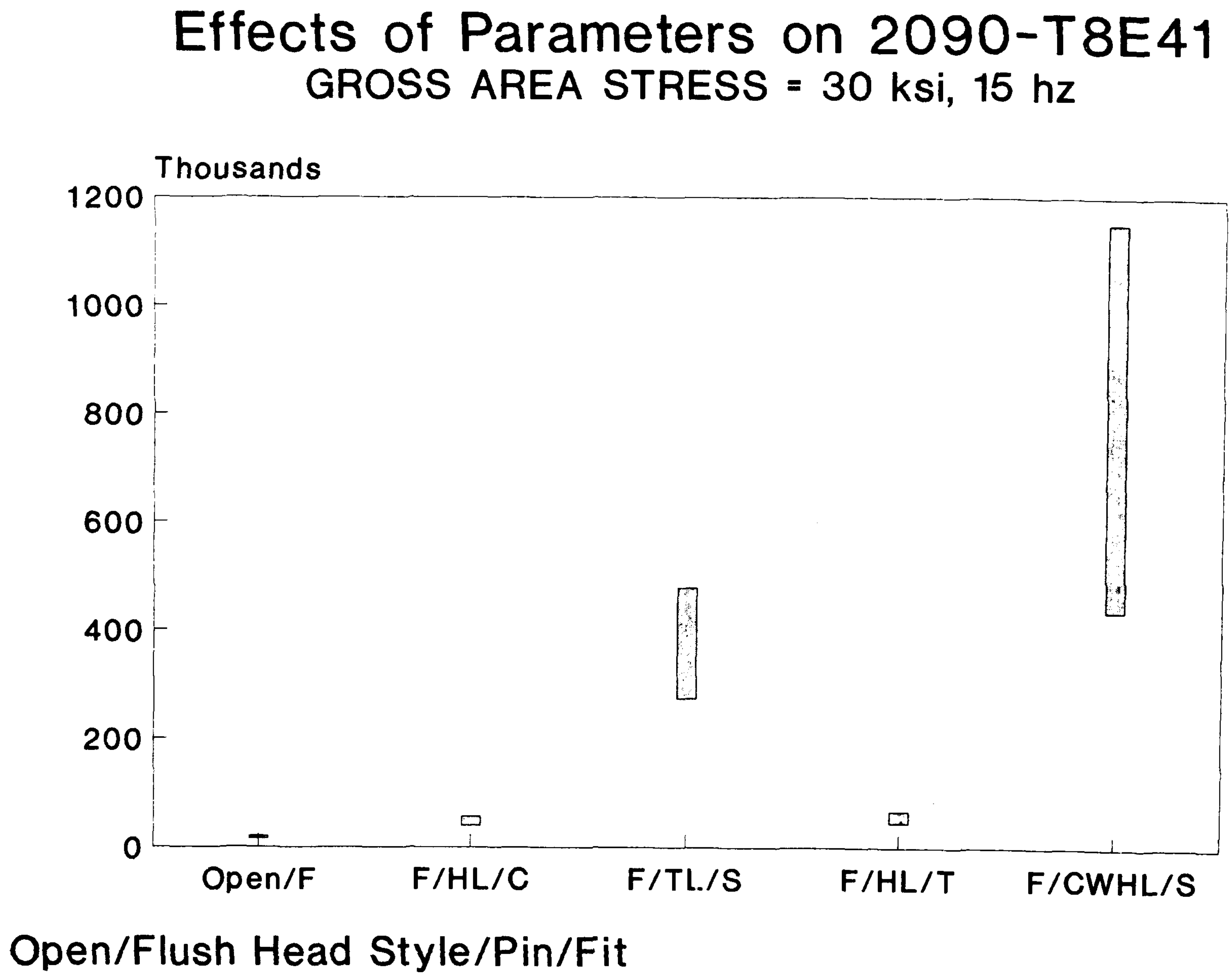


Fig D-7. Effects of Parameters on 2090-T8E41

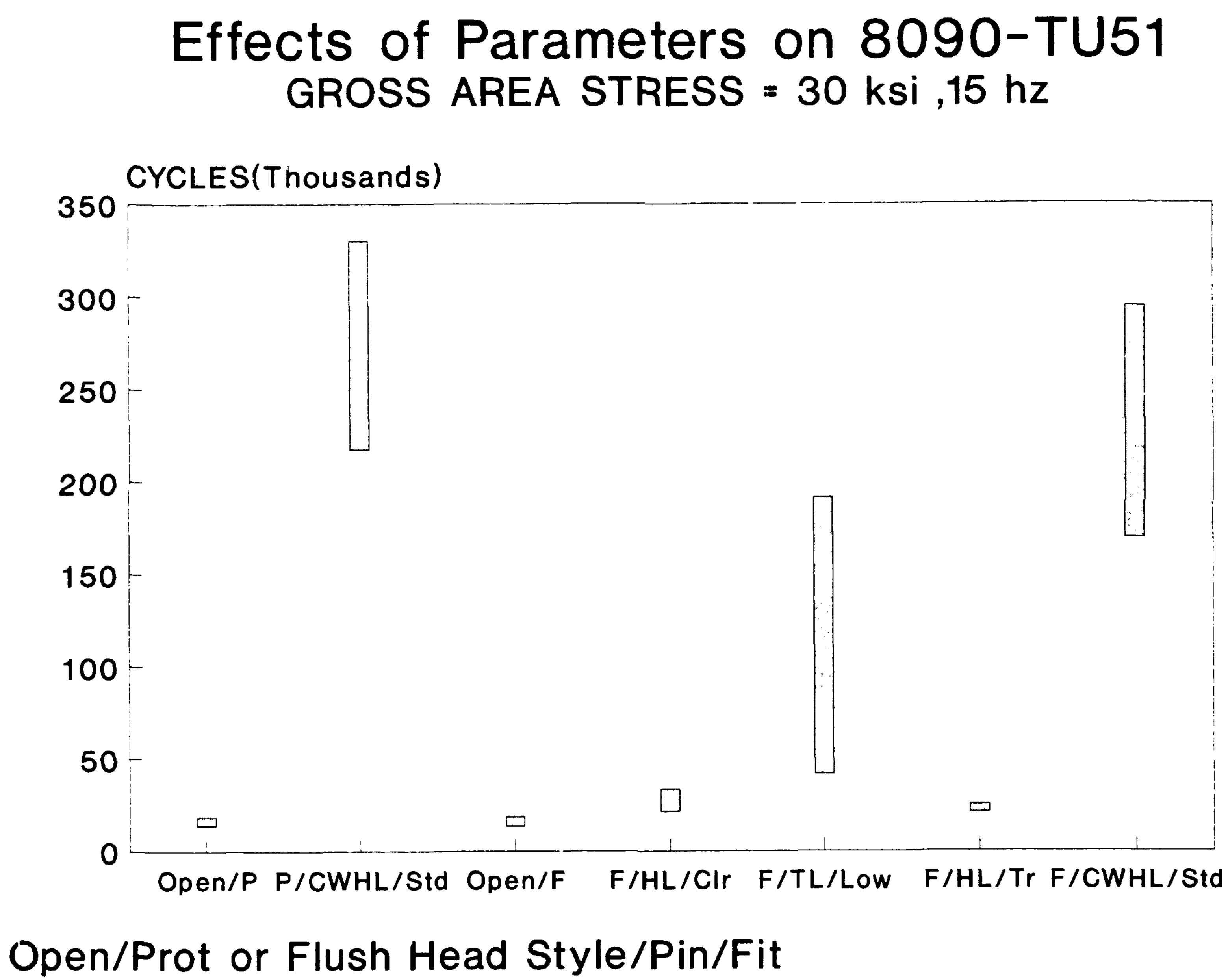


Fig D-8. Effects of Parameters on 8090-TU51

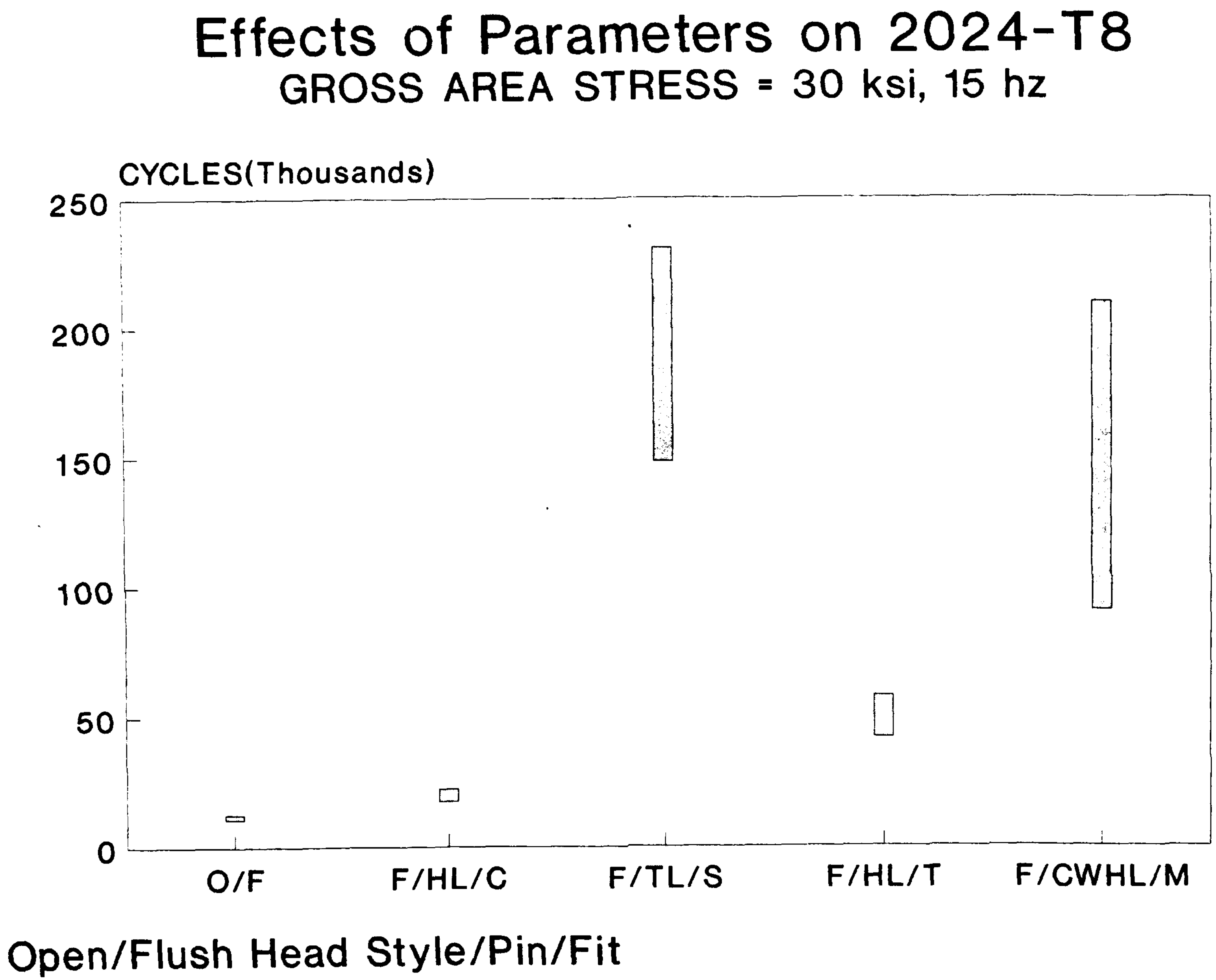


Fig D-9. Effects of Parameters on 2024-T8

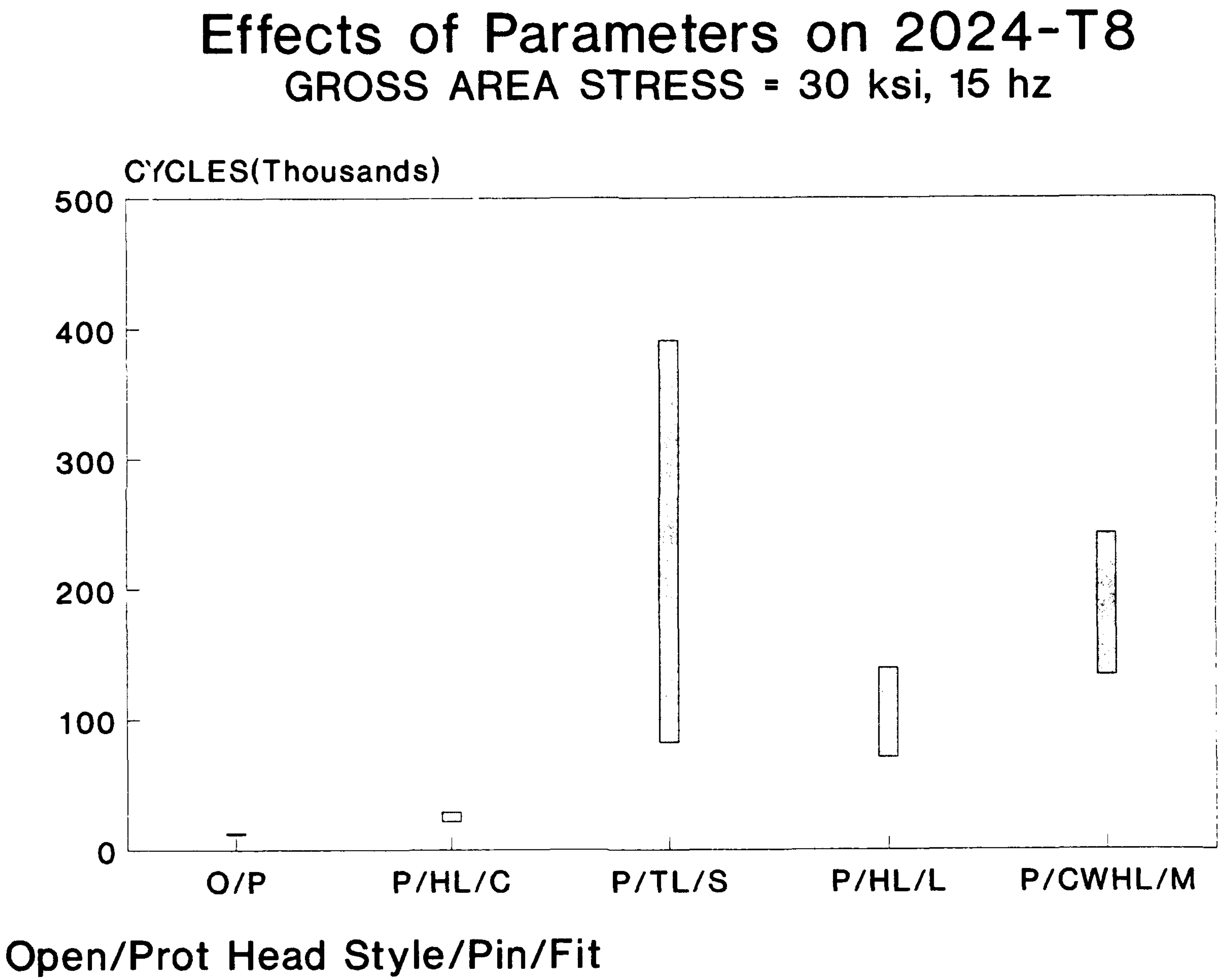


Fig D-10. Effects of Parameters on 2024-T8

Fig D-11. 8090-TU51 Fatigue Test Coupons (L-ST orientation)

Fig D-12. 2090-T8E41 Fatigue Test Coupons (L-LT orientation)

Fig D-13. 2024-T8 Fatigue Test Coupons
(L-LT orientation)

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